The utilisation of potato flour in pasta production: the effect of starch-protein interactions on the physical chemical properties, and *in vitro* digestion behaviour, of potato enriched pasta

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Declaration

Presentations

1. Pasting and starch digestion of potato flour. A poster presentation at **Riddet Institute *Conference*, Wellington, from 10th to 12th July 2018.**

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by

Song Yang

Potato (*Solanum tuberosum L.*) is consumed throughout the world and regarded as a carbohydrate rich staple food, ranking behind rice, wheat, and maize as the fourth most important global crop. The potato is not only used as a vegetable, but also as the source of raw materials for processing into starch derivatives production. Potato flour can be preserved for a long time, due to its low moisture content, and it can maintain the nutrition and flavour of fresh potato. Potato flour is rich in the necessary nutrients for the human body and can be substituted for wheat flour in the preparation of new types of food to meet the requirement of people for nutritional staple foods. Potato is classified as a high glycaemic index (GI) food, and gluten free. The addition of potato flour affects the functional nutrition and digestion characteristics of flour products. Therefore, in order to provide a theoretical basis and technical support for the application of potato flour in pasta, this dissertation studied the effects of potato flour on the functional nutrition and digestion characteristics on pasta and the interaction between starch and protein.

In this study, two different types of potato (Agria and Nadine), in combination with wheat flour (Semolina), were used as the main raw materials for the production of pasta and gels. The research investigated the effect of different treatment methods on the physicochemical, pasting and digestion properties of potato flour. Potato was used as raw potato flour, potato flour which from cooked potatoes, and cooked and frozen potato flour derived from cooking potatoes and then subjecting the potatoes to blast freezing before being made into flour.

In total, six different kinds of potato flour were made, three different processing parameters for both the Agria and Nadine potatoes. These were mixed with wheat flour at different proportions to make a range of potato and wheat flour blends. The textural and pasting characteristics of the blends were determined. Pasta was made using the potato and wheat flour blends. The texture of the potato flour pasta was found to be weaker than the control pasta samples. In order to improve these textural characteristics, soy protein was added to the pasta mixes at different proportions. The viscosity and digestion properties and the quality of pasta were determined.

The proximate analysis, pasting, and digestibility properties of raw, cooked, and cooked-frozen potato flour were determined. The cooked and cooked-frozen process significantly ($P < 0.05$) decreased the content of total starch, amylose content, and resistant starch (RS), while influenced water solubility index (WSI), water absorption index (WAI) and swelling capacity (SWC). It also increased ($P < 0.05$) the dietary fibre markedly. The pasting properties of potato flour were studied by a Rapid Visco Analyser (RVA), the viscosity of the cooked potato flour was found to be higher than those of raw, and the cooked-frozen potato flour, but showed the lowest pasting temperature. *In vitro* digestion of the RVA samples was conducted to measure the predictive glycaemic response in potato flour. The process of forming a gel via the RVA significantly increased the rate of starch digestion, and the total area under the curve (AUC). The AUC was calculated as the amount of reducing sugar released from a 120 min *in vitro* glycaemic digestion process (mg reducing sugar/ mg sample) × min] and was used to compare the predictive glycaemic response of potato flour pasta and gels.

The functional and pasting characteristics of wheat flour, and their blends with three different treatment of potato flour at 10 to 50% were investigated in this study. The effect of the characteristics of the mixtures were studied in terms of change to the protein, total starch, amylose, dietary fibre, resistant starch, solubility, swelling capacity, water absorption, and pasting properties. The results showed that the moisture, protein and amylose content decreased with the increasing proportion of potato flour used, and that the total starch, dietary fibre and resistant starch showed a gradual increase with the level of potato flour added. Compared with wheat flour, potato flour had a higher

pasting characteristic and lower solubility. The addition of potato flour increased the WSI, WAI, and SWC of the blends, the peak viscosity, final viscosity and setback increased with an increase in the potato flour from 10%-50%.

In conclusion, the effect of substitution of durum wheat semolina with two local cultivars of potato (Agria and Nadine) flour on viscosity, digestion properties and the quality of pasta was investigated. Compared with durum wheat semolina pasta, the cooking loss was significantly increased by adding potato flour but there was a decrease in WAI. Supplementation of potato flour also influenced the texture properties of potato-wheat pasta, the addition of potato flour increased the firmness and as the amount added increased and then decreased, the potato flour pasta made with 30% had a stable structure. In addition, all enriched pasta with potato flour showed a significant increase in reducing sugar released during an *in vitro* digestion and standardised AUC values compared to control pasta. Fortification improved the pasting and nutraceutical of pasta products and promoted the processing of potato staple food.

Keywords: wheat flour, potato flour, soy protein, four blends, pasta, physiochemical, RVA, viscosity, starch digestibility,

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Chapter 1

Introduction

1.1 Background

Potatoes *(Solanum tuberosum L.)* are native to Peru and Chile, and are found to grow at 3,000-4,000 meters above sea level in the Andes mountains of South America (Rhoades & Bebbington, 1990). Today, potato production has increased dramatically all over the world. Potatoes are an important food and vegetable crop both in developing and developed countries to meet the demands of increasing human population (Birch *et al.*, 2012).

Potatoes are also an important source of carbohydrates that are consumed throughout the world, and are behind rice, wheat, and maize in overall global production (Tian, Chen, Ye, & Chen, 2016). Besides being a valuable source of carbohydrates, and therefore an energy source, potatoes also contain other nutrients that are required in the diet, such as vitamins, minerals, and antioxidants (Arun *et al.*, 2015; Burlingame, Mouille, & Charrondiere, 2009). Potato tubers contain about 0.2% fat, which makes potato a low-fat food. The protein content of a potato is about 10%, similar to the protein content of wheat flour, and higher than that of rice and corn (Bártová, Bárta, Brabcová, Zdráhal, & Horáčková, 2015). Compared with other vegetables and food crops, the amino acid composition in potato protein is significantly higher than the recommended value of FAO/WHO essential amino acid content, and potato protein is rich in lysine, which is deficient in other food crops (Bártová *et al.*, 2015; Lutaladio & Castaldi, 2009).

Compared with other food crops, potatoes can grow in harsh weather conditions, lack of water resources, poor land environments, and maintain high yield, giving potatoes a high economic value (Zhang, Fen, Yu, Hu, & Dai, 2017). As a matter of fact, with the steady growth of the world's population, demand for primary agricultural products has increased, but production capacity has not. Therefore, food production is under a lot of pressure, and there is an urgent need to adjust staple food production and reduce the stress on food demand (Mu & Sun, 2017).

Most of the potatoes are consumed fresh, being baked, boiled, and fried in a variety of recipes. However, global consumption of potato as food is shifting from fresh potatoes to added-value processed food products, the main items in that category are frozen potatoes and potato chips (Zhang *et al.*, 2017).

Therefore, to increase the proportion of potato in the daily food intake of people, it is necessary to consider the dietary habits of consumers and develop new potato staple foods such as bread and pasta, as these products are popular with consumers. The development of the potato as a staple food could ease resource and environmental pressures and comply with the growing nutritional and health needs of the population.

Starch, as the main form of potato processing, not only causes the loss of potato nutrients, but also creates a certain degree of pollution to the environment (Pu, Qin, Che, Zhang, & Xu, 2014; Vikelouda & Kiosseoglou, 2004; Waglay, Karboune, & Alli, 2014). Compared with potato starch, potatoes flour has more comprehensive nutritional profile (Elżbieta, 2012). Potato flour has been used because of its nutritional characteristics and processed into a variety of foods, such as flavoured mashed potatoes, frozen fried chips, various flavour crisps, baked foods and snacks (Bártová *et al.*, 2015; Kulkarni, Govinden, & Kulkarni, 1996; Li *et al.*, 2018; Liu, Mu, Sun, Zhang, & Chen, 2016).

Potato flour is a powdery product obtained from the raw potato tuber which has been processed through a series of techniques. Potato flour includes not only the basic nutrients of fresh potato but also some functional components. The low moisture content, long shelf life, easy storage, and transportation make potato flour easy to use in a range of situations (Lingling, Yange, Shuangqi, Yanbo, & Fuqiang, 2018; Zhang, Wheatley, & Corke, 2002).

The basic potato flour production process follows a standard protocol, as shown in Figure 1.1, the potato is harvested, cleaned, peeled, sliced, protected against colour loss, dried, milled, sieved and then packaged (Lingling *et al.*, 2018).

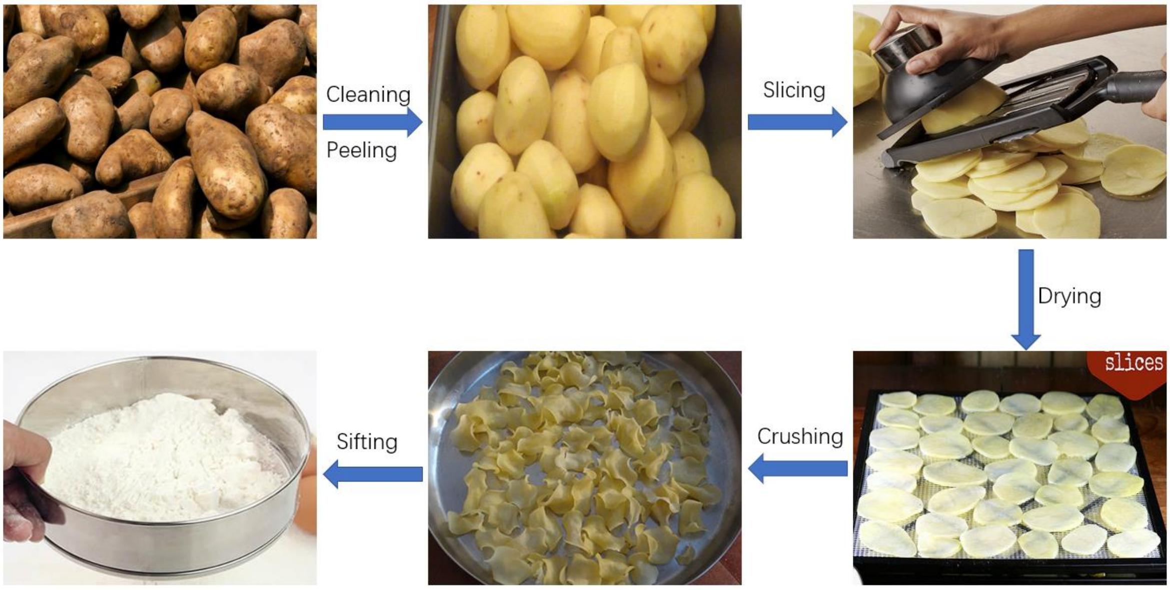


Figure 1.1 The basic production process for potato flour production.

Potato flour is difficult to form into a dough which matches the characteristics of wheat flour, and has poor processing performance (Liu *et al.*, 2016). Wheat is one of the leading food crops in the world, with the world's total output accounting for 27.4% of the whole food crop and 52.9% of the whole food yield. The population of more than 40 countries depend on wheat flour as the main food source, so wheat flour plays an important role in the security of food consumption (Shewry & Hey, 2015). In western countries, wheat flour is processed into bread and biscuits, while in Asian countries, wheat flour is mainly processed into noodles and steamed buns.

Noodles are the most common traditional food in the world, have become one of the world's two most significant flour products, second only to bread in its annual output (Shewry & Hey, 2015). There are many types of noodles in the world. Depending on the region where they are produced and eaten, they can be divided into two types: pasta and noodles (Fu, 2008). Pasta and noodles are staple food products in many countries. They differ from each other in many aspects, however, the main difference is the "raw material" used for their production. Pasta is usually produced from durum wheat semolina, whereas noodles are produced either from ordinary wheat flour or starches from different sources (Chen *et al.*, 2002).

Traditionally, being an Italian product, pasta has become a worldwide consumed product due to its ease of transportation, handling, cooking, and long shelf life (Petitot, Boyer, Minier, & Micard, 2010). The most common method of producing pasta is extrusion. In this process, flour is mixed with water, resulting in the formation of a dough that is forced through a die and then dried (Sozer, 2009).

1.2 Aim of Research

The aim of this research was to investigate two cultivars of potatoes (Agria and Nadine) flour were treated by gelatinisation, subjected to further retrogradation, and then incorporated into semolina pasta. The physicochemical properties and pasting of potato flour, wheat flour, and their blends with potatoes flour at 10 to 50%, were measured. The changes to the characteristics of the mixture were studied in terms of variations in protein, total starch, amylose, dietary fibre, resistant starch, solubility, swelling capacity, water absorption, and pasting properties. Further research focused on determining the influence of the inclusion of potatoes flour and soy protein on the physiochemical and nutritional quality of pasta. One of the aims of these tests was to determine what replacement level, if any, may be acceptable both from a physicochemical and pasting perspective.

1.3 Objectives of Research

The objectives of the study were to:

1. Six potato flours were obtained through three different processing methods, and the physicochemical, viscosity and digestion properties of these 6 potato flours were compared in order to provide a reference for the application of potato flour.

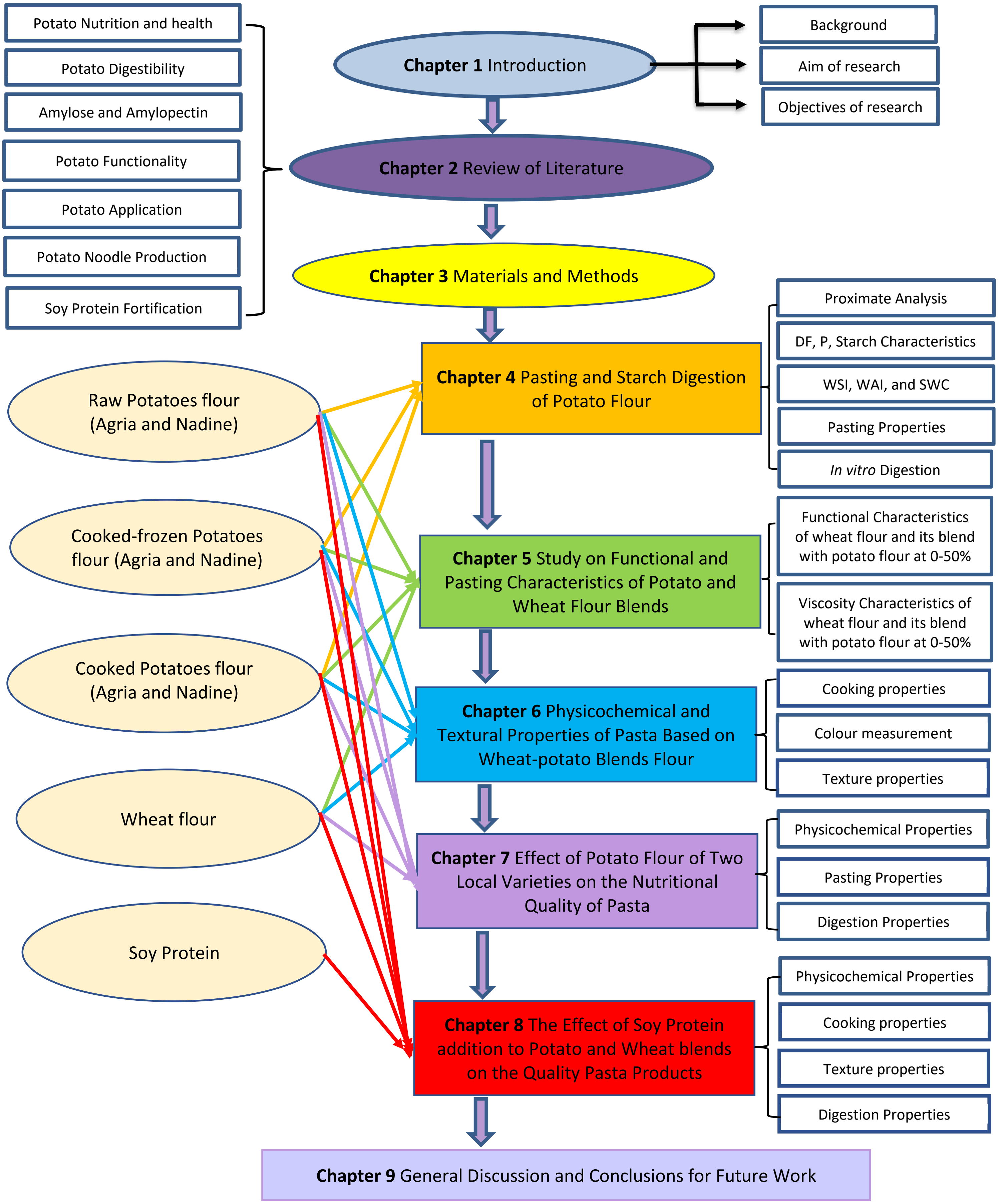
2. The mixing of different potato and wheat flour mixtures were evaluated to provide a basis for the application of blends in food products.

3. The application of potato flour in pasta was investigated, and the physicochemical and texture properties of potato pasta were determined to provide a reference to consumer acceptability.

4. The nutritional aspect (mainly glycaemic load) of the potato enriched pasta was determined to evaluate the advantages and disadvantages of potato pasta.

5. The nutritional characteristics of this new type of pasta by adding soy protein to potato pasta to promote the application of potato as a staple food and meet people's demand for a new kind of food.

1.4 Thesis structure



Chapter 2

Review of Literature

This chapter summaries the current literature on the physicochemical properties and nutritional value of potato. This chapter begins with a summary of the research regarding the nutritional benefits of potatoes and the health risks associated with them. This focuses primarily on the relationship between potato starch digestibility and blood sugar response. The classification, composition, digestion, function, and application of potato starch in food are also evaluated in terms of a mechanistic approach to human nutrition. Thus, this chapter introduces the application of potato in flour products, and the effect of potato powder on the digestion, blood sugar reaction and cooking quality of cereals such as pasta and noodles. Based on the observation of previous research findings, the development of potato staple food in the future is discussed.

2.1 The Potential use of Potato as a Staple Food: Nutritional Benefits and Controversial Associations With Health Risk

The potato *(Solanum tuberosum L.)* is an herbaceous crop product treated as an annual that develops up to 100 cm tall and produces a tuber. The tubers come in thousands of different sizes, colours, cooking characteristics, and flavours. Potatoes, and processed potato foods, are an important part of the diet, and have been a staple food in populations across the globe for over 10,000 years (Zhang, Fen, Yu, Hu, & Dai, 2017).

As per the Food and Agriculture Organization Statistical Databases of United Nation (FAOSTAT), potatoes account for approximately 2% of the world's dietary supply (FAO, 2009). China is presently the world's biggest potato producing nation, followed by India, Russia, the USA, and Ukraine. China and India together account for around 1/3 of worldwide potato generation and it is anticipated that this figure will be higher in future years. The consumption of potato has also increased in developing countries from 10 kg to 22 kg per capita during 1960–2008 (Avendano, 2012). Potatoes are processed in various forms before being consumed, including crisps, French fries, baking and mashing.

Potatoes are an affordable food alternative and are regarded as a carbohydrate rich food. They are an important source of dietary nutrients, minerals, and phytonutrients (Singh & Kaur, 2016). Potatoes are a good source of a few essential supplements such as protein, vitamin C, vitamin B6, magnesium, potassium and fibre. For example, a 100 g white potato provides 390 kJ (93 kcal) dietary energy primarily from carbohydrates, and exceptionally small of which is from fat and proteins (Zaheer & Akhtar, 2016). The nutrient content of 100 g (FW) of potato are shown in Table 2.1.

Cooked potatoes are an excellent dietary source of carbohydrates, which make up about 75% of the total dry matter of the tuber. Starch is the main carbohydrate in potatoes. Cultivated potatoes have between 11.0–30.4% starch on a fresh weight basis (mean of 18.8%), while wild species can have up to 39.6% of starch (Jansen, Flamme, Schüler, & Vandrey, 2001).

Potato protein ranges from 1–1.5% of fresh tuber weight (Ortiz-Medina, 2006). Potatoes do contain proportionally more lysine than cereal proteins, while the sulphur-containing amino acids (methionine and cystine) are at lower levels. Chakraborty, Chakraborty, and Datta (2000) described genetically modified potatoes which were created to contain 35–45% more protein than control, with 2.5 to 4-fold expanded higher lysine, methionine, cysteine, and tyrosine contents.

Table 2.1 The Nutrient content of 100 g (FW) of potato

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Adapted from (Camire, Kubow, & Donnelly, 2009)

Lipids a minor component of potato weight, representing approximate 0.15 g/150 g of raw weight, less than cooked rice (1.95 g), or pasta (0.5 g) (Haase & Haverkort, 2006). Dietary fibre is provided by cell walls, particularly the thickened cell walls of the potato peel, which makes up 1–2% of the tuber. These nonlignified fibres may have a part to play in decreasing cholesterol levels (Lazarov & Werman, 1996).

The potato is a vital food security crop and can replace cereal crops. Therefore, it has been hoped that potato utilization could help with the security of staple food items by partially replacing wheat, rice, or corn with potato flour in traditional staple foods. However, most potatoes are eaten as cooked fresh vegetables and are not processed industrially. Potatoes account for less than 10 percent of total production as the primary raw material for processed products in the form of starch, modified starch, potato chips, and fried chips (Zhang *et al.*, 2017).

Whereas potatoes play an essential part in food security, refined potato products processed by the food industry are at the same time related to numerous inadequacies of the Western diet by being associated with high fat, salt, and GI. These impacts are frequently related to the nature of the processing techniques employed in converting raw potatoes into potato products. Camire *et al.* (2009) and King and Slavin (2013) discussed the relationship between potatoes and human wellbeing, with a focus on the potatoes overall, and, to a limited extent, commonly consumed products. Potatoes in the commitment of bioactive supplements and phytochemicals have been associated with several health benefits (Figure 2.1).

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Figure 2.1 Schematic representation of the connections between potato phytochemicals, micronutrients, macronutrients, and human health impacts.

Adapted from (Furrer, Chegeni, & Ferruzzi, 2018)

Despite the potential benefits associated with consumption of nutrients found in potatoes, there is a current debate concerning epidemiological affiliations regarding the utilization of potato, as a high GI food, and diabetes risk. Halton *et al.* (2006) observed a positive association of consumption of both potatoes and French fries and an increase occurrence of type 2 diabetes after researching 84,555 women who had no history of chronic disease at baseline. Muraki *et al.* (2016) studied the association of potato consumption and risk of type 2 diabetes in a study of 3,988,007 person-years of follow-up, illustrating that 15,362 new cases of type 2 diabetes were identified. Higher consumption of potatoes was significantly associated with a raised risk for type 2 diabetes. More recent studies have shown that total potato consumption is not identified with risk for some chronic diseases but could represent a little increment in risk for type 2 diabetes and hypertension (Schwingshackl, Schwedhelm, Hoffmann, & Boeing, 2019).

In previous observational studies, higher consumption of potatoes has been positively associated with the risk of type 2 diabetes, hypertension, or colorectal cancer (Borgi, Rimm, Willett, & Forman, 2016; Larsson & Wolk, 2016; Muraki *et al.*, 2016). However, potatoes play an important role in the world's staple foods, belong to the most frequently consumed plant-based food groups worldwide. Potatoes are considered to be a starchy vegetable, leading people to focus on their contribution as a source of carbohydrates (Jansky, Navarre, & Bamberg, 2019). Besides, the fact that potatoes are sources of important substances such as fibre, potassium, vitamin C, and micronutrient may mitigate some of their anti-nutritional properties (Beals, 2019; Leo *et al.*, 2008).

For instance, given their high potassium and low sodium content, potatoes would appear to be perfect nourishment to incorporate into a dietary design for overseeing hypertension. Few studies have inspected the relationship of potatoes to blood composition or hypertension treatment. A recent epidemiological report considered utilizing information from Harvard's well known Nurses' Health Study I and II. The conclusion was that a "Higher admissions of prepared, bubbled, or squashed potatoes and French fries was related with an increased risk of hypertension" (Borgi *et al.*, 2016). Vinson, Demkosky, Navarre, and Smyda (2012) demonstrated that potatoes may affect blood composition and body weight. There is, as of now, a need for experimental data concerning the mechanistic effect of potato consumption on obesity, weight management, and diabetes.

2.2 The Association Between Starch Digestibility and the Glycaemic Response of Potato Foods

Starch is the primary stored carbohydrate in food crops and is also an important dietary component in processed foods (Sasaki & Kohyama, 2011). The digestibility of starch is closely related to human health, and the digestion rate is also associated with many chronic diseases (Birt, Diane F., *et al.,* 2013). Research on the digestibility of starch not only reveals the diseases linked to the metabolism of the body, but can provide dietary guidelines for human nutrition. As starch is the main dietary component affecting glycaemia, much research has been published on the impact of postprandial glycaemia on the aetiology of chronic metabolic diseases such as obesity, diabetes and cardiovascular disease (Englyst, Veenstra, & Hudson, 1996; Englyst, Vinoy, Englyst, & Lang, 2003; Blaak *et al.*, 2012).

Many factors affect the digestibility of starch, such as the intrinsic properties of starch, including structure (Englyst, Englyst, Hudson, Cole, & Cummings, 1999) and the ratio of amylose to amylopectin (Sasaki *et al.*, 2009), the degree of processing (Simsek, Ovando-Martínez, Whitney, & Bello-Pérez, 2012), and the presence of other nutrients such as fat, protein, and dietary fibre (Cleary & Brennan, 2006a). According to these studies, starch-based foods are mainly divided into slowly digested products, such as pasta, wholegrain cereals and legumes, and rapidly digested products, such as bread, breakfast cereals, and potatoes (Svihus & Hervik, 2016).

According to the digestion rate in the body, starch is able to be divided into three categories, including rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). RDS is the starch that is digested rapidly (<20 min) in the small intestine, which results in a relatively high postprandial glycaemic response. On the contrary, SDS is digested at a slow rate and is absorbed in the small intestine completely and slowly. RS is not assimilated in the small intestine, but it can be fermented in the large bowel (Englyst, Kingman, & Cummings, 1992). The glycaemic response in human blood is significantly associated with the digestion rate of starch in food (Englyst *et al.*, 1996). Many researchers have proved that RDS is quickly absorbed by our digestive system and rapidly raises our blood sugar levels. A diet that is rich in rapid increases in blood sugar is associated with many metabolic-related chronic diseases, especially diabetes and obesity (Brennan, 2005a). Meanwhile, SDS and RS have been found to have physiological functions that may assist in preventing diabetes and obesity, some kinds of cancer, cardiovascular disease, colonic health, and osteoporosis (Lehmann & Robin, 2007; Sajilata, Singhal, & Kulkarni, 2006).

Since 1981, the glycaemic index (GI), which is based on the postprandial glycaemic response, has been used to classify carbohydrate rich foods according to how they affect blood glucose levels (Jenkins 2007; Jenkins *et al.*, 1982). Foods with a GI value of above 70 are classified as high GI while those and ranging from 56 to 69 are regarded as and medium-GI foods. In contrast, foods that have a GI of 55 or lower are classified as low GI products (ISO Standard 26642, 2010). Studies also reveal that the regular intake of low GI foods may decrease the incidence and prevalence of heart disease, diabetes, and some forms of cancer (Brand-Miller, 2007; Wolever & Mehling, 2002). Therefore, knowledge of the GI value of foods can help the health-conscious to design their diets more effectively, thus improving their health, which provides certain theoretical significance and practical value in the research and improvement of the new product.

However, the GI value of potato has been found to be influenced by both the variety, and the processing method (Fernandes, Velangi, & Wolever, 2005; Soh & Brand-Miller, 1999). Fernandes *et al.* (2005) reported that the GI values of North American potatoes ranged from 56 to 89. More recently another researcher (Henry, Lightowler, Strik, & Storey, 2007) reported that the GI values of potatoes ranged from 56 to 94 by investigating eight potato varieties in the UK.

Freshly cooked potato starch contains plenty of RDS (Leeman, Bårström, & Björck, 2005). Additionally, it has a high GI, resulting in the increasing risk of chronic disease (Atkinson, Foster-Powell, & Brand-Miller, 2008). Therefore, in order to reduce the GI value of potatoes, different processing methods have been investigated by some nutritionists, the results illustrate that cooling and cold storage is most significant (Monro, Mishra, Blandford, Anderson, & Genet, 2009; Tahvonen, Hietanen, Sihvonen, & Salminen, 2006).

Table 2.2 illustrates that cooking and refrigerating cooked potatoes increases the content of SDS and RS compared to that of freshly cooked potato, indicating that cooking methods would be useful to reduce the GI value of potato starch. The increasing content of SDS and RS has been attributed to amylose retrogradation (Ek, Brand-Miller, & Copeland, 2012; Karlsson, Leeman, Björck, & Eliasson, 2007). Amylose molecules tend to retrograde, leading to resistance in enzymatic digestion and absorption in the small intestine. Besides, there is a negative relationship between the amylose content of starch and the gelatinisation temperature and peak viscosity (Nayak, Berrios, & Tang, 2014). Therefore, the rate of digestion of potato starch is associated with the amylose: amylopectin ratio. Amylose content in potato affects starch digestion and the GI of potato.

Table 2.2 The effect of cooking on starch fractions of New Zealand potatoes

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Bulked sample of three tubers analysed in duplicate. Values are expressed on a wet weight basis.

Adapted from (Monro, *et al.*, 2009)

There is considerable interest in the way starch digestibility is controlled by the levels of SDS or RS, which affects both glycaemic control and the utilization of the entire microbial population in the intestine. The degree of SDS and RS in potato products can depend on the type and degree of processing (Thed & Phillips, 1995), and the manner in which they consumed (Englyst & Cummings, 1987). Resistant starch is classified into four types: RS1- Physically inaccessible starch (e.g., in partly milled grains and seeds); RS2- Ungelatinized starch granules that resist digestion by amylases (e.g., the native semi crystalline starch granules in raw potatoes, green bananas, and high-amylose corn); RS3- retrograded starch resulting from cooked and cooling starch after gelatinization; and RS4- chemically modified starches to improve the functional characteristics of the starch (Englyst, Kingman, & Cummings, 1992). In particular, since raw potato starch is a rich source of RS2, the degree of initial gelatinisation through thermal treatment processing or cooking is a critical first step. The strategy of retaining some starch granules and RS2 structure may increase the relative content of RS in finished potatoes. Some studies have shown that cooking methods that provide sufficient water and heat for the complete gelatinisation of starch may improve digestibility compared to dry heating methods, such as baking and frying (García-Alonso & Goñi, 2000; Lunetta, Di Mauro, Crimi, & Mughini, 1995). But others have found that the cooking methods had no effect on the glycaemic response (Soh & Brand-Miller, 1999). Studies have shown that the cooling of gelatinised potatoes produces considerable levels of SDS and RS3 *in vivo* and lowers the GI (Monro, *et al.*, 2009). Interestingly, the decrease in the GI was still observed after reheating, compared to the products consumed immediately after cooking (Tahvonen, Hietanen, Sihvonen, & Salminen, 2006). RS content is also increased by temperature cycling or by repeated heating and cooling sessions (Leeman, Bårström, & Björck, 2005).

The internal and external potential factors that may affect the digestibility of starch are shown in Figure 2.2. The internal factors of amylose include the quality of starch, the proportion of amylopectin, and the phosphorylated starch (Phosphorylation is the only naturally occurring covalent modification of starch revealed so far) and other components such as polyphenols. External factors include storage, cultivation conditions, cooking, and cooling. Cooking after cooling not only affects nutrients such as water, it also affects the starch structure of the starch digestibility.

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Figure 2.2 Possible factors affecting starch digestibility in potatoes

Adapted from (Wang & Copeland, 2013)

The GI appears to be a good indicator of carbohydrate quality but is still controversial as a measure of the health effects of starch-based foods. Glycaemic load (GL) is another value developed to describe the carbohydrate digestibility of foods in the context of general consumption. The GL is the GI of foods that are normalized by the carbohydrate content of the average portion and can be compared among foods. The total glycaemic load of potato products is generally lower than the value of starchy foods, including pasta and white rice, but higher than wheat bread and several fruits, vegetables, and beans (Foster-Powell, Holt, & Brand-Miller, 2002).

There are other factors (such as potato variety and maturity) that can affect the glycaemic response of potato-based foods (Fernandes, Velangi, & Wolever, 2005). As mentioned previously, the glycaemic response of potato is also influenced by the method of preparation, including the degree of processing and the degree of the addition of ingredients (Raigond, Ezekiel, & Raigond, 2015).

The popularity of processed potato products in the food supply and diet is for the use of new varieties or processing techniques to limit negative nutritional properties (fat and sodium) while optimizing positive properties (phytochemical content, micronutrient retention and RS). As our understanding of the nutritional properties and quality of potato products increases, it is important to recognise that processing will be a critical factor in delivering nutritionally enhanced products to consumers.

2.3 The Role of Amylose and Amylopectin in Starch Degradation

Potatoes have a high GI, and the GI may be determined by the amylose: amylopectin ratio (Jansky & Fajardo, 2016). Amylose is primarily a linear chain of D-glucose units linked by α-1$\rightarrow$4 linkages. Amylopectin is more branched and is considered by starch chemists as one of most important molecules in nature. The molecular weight of amylopectin is 100 times higher than that of amylose (Zobel, 1988). As compared to amylose, the amylopectin structure is more complex because of the extensive linkages forming branches (Figure 2.3). Generally, potato starch is a mixture of the two polysaccharides, amylose and amylopectin, consisting of 25–30% amylose and 70–75% amylopectin (Zhao, Andersson, & Andersson, 2018). Lehmann and Robin (2007) reported that high amylose was associated with high levels of RS in processed starchy food.

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Figure 2.3 The molecular structure of amylose and amylopectin

Molecular structure of amylose (a) and amylopectin (b); in the case of (a), n denotes a repeating structure to form a chain (Dupuis & Liu, 2019).

Foods with a high amylose content can lower glycaemic and insulin index compared to foods with a high amylopectin content (Jansky & Fajardo, 2016). A high amylose diet also improves colon function and lowers triglyceride and cholesterol levels (Behall, Scholfield, Yuhaniak, & Canary, 1989; Regina *et al.*, 2006). The ratio of amylose to amylopectin affects the properties of potato starch, such as digestibility, gelatinisation temperature and viscosity (Schirmer, Höchstötter, Jekle, Arendt, & Becker, 2013). Leeman, Karlsson, Eliasson, and Björck (2006) studied potato starches containing different proportions of amylose, and found that the treatment conditions were of little importance to the formation and hydrolysis of RS, whereas a higher amylose content provided a lower hydrolysis index (HI) and a higher RS content than starch with less amylose. So retrogradation of amylopectin helps lower the HI. Potato starches with high amylose content have RS content of 25% to 30%, while other starch content is 0% to 5%. High amylose contents can lead to a substantial decrease in the expected GI.

The proportions of amylose and amylopectin vary among plant species, depending on plant development and growth conditions. The ratio of two starch components affects many properties of starch, such as swelling ability (Hermansson & Svegmark, 1996), water solubility (Sandhu, Singh, & Malhi, 2005), water binding ability (Sandhu *et al.*, 2005), barrier properties and mechanical (Stading, Hermansson, & Gatenholm, 1998), and microscopic properties of the starch film (Hermansson & Svegmark, 1996). Generally, these authors found that amylose was digested more slowly than amylopectin and that in high amylose meals, blood sugar and insulin levels are lower, and satiety lasts longer.

Amylose content can be determined in different ways. Scott, Jane, and Soundararajan (1999) used differences in carbon isotope ratios between amylose and amylopectin. In general, natural materials contain low ^{13}C content, and the difference between amylose and amylopectin is minimal. Near-infrared (NIR) spectroscopy can estimate the ratio of these two components (Fertig, Podczeck, Jee, & Smith, 2004). Due to the overlap of absorptivity between various components, it is difficult to achieve the calibration of single-wavelength absorptivity and concentration map using NIR spectroscopy. The simplest calibration model is usually based on multiple linear regression, using the absorbance of two or more wavelengths (Fertig *et al.*, 2004). The near-infrared spectrum often shows the baseline displacement, which is caused by the change of sample compactness and the scattering from the particle surface. In order to minimize the impact of these parameters, mathematical pre-processing of the original spectra is usually performed before the development of the calibration model. High-performance chromatography has been widely used to estimate the relative contents and apparent molecular weights of amylose and amylopectin in natural starches (Jackson, Choto-Owen, Waniska, & Rooney, 1988). However, this technique is time-consuming and not suitable for routine analysis. The enzymatic method is highly accurate, and most of the current market uses the amylopectin k-amyl kit purchased from Megazyme in Ireland to test the enzyme according to the assay procedure. The disadvantage is that it is expensive and time-consuming.

2.4 Potato Starch Functionality in Food Systems

The most critical problems of using fresh potatoes are their perishability and non-storability caused by water content and metabolic activity after harvest (Pinhero, Coffin, & Yada, 2009). Besides, even under good conditions, the thin, permeable potato skins are most likely to suffer from excessive weight loss, bud growth, and deterioration (Kaur, Singh, Ezekiel, & Sodhi, 2009). Converting potatoes into potato flour can extend the shelf life of potatoes and reduce storage costs. Starch is the main carbohydrate in potatoes or potato flour and a valuable agricultural commodity with many food and non-food uses (Ellis *et al.*, 1998). Starch has many useful properties for food and non-food applications, including thickening, coating, gelling, binding, and encapsulation. The essential functions of starch are swelling, gelatinisation and retrogradation properties (Dupuis & Liu, 2019). Many advanced analytical techniques have been used to characterize the function of potato starch. However, the actual value of potato starch functionality varies with the potato source and the analytical methods used.

2.4.1 Swelling power and solubility

When starch is heated in an abundance of water, the crystal structure is destroyed (due to the breaking of hydrogen bonds), and the water molecules bind with the exposed hydroxyl groups of amylose and amylopectin through hydrogen bonds, resulting in particle swelling and increased solubility (Tester & Morrison, 1990). Swelling and solubility are the results of the interaction between amylopectin, and the degree of their communication is affected by the amylose/amylopectin ratio, and the properties of amylose and amylopectin in terms of molecular weight, distribution, degree, and length of branching, and conformation. Amylose - lipid complexes have been shown to inhibit swelling and dissolution (Swinkels, 1985).

Table 2.3 Swelling power and solubility of tuber and root starches

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Adapted from (Hoover, 2001)

The higher swelling power and solubility of potato starch (Table 2.3) may be due to the higher content of phosphate groups on amylopectin (Galliard, 1984). Other starches are generally lower in swelling and solubility (at 95°C), 14.6 -51, and 7.8 -26.7, respectively.

2.4.2 Gelatinisation and pasting behaviour of starch

Native starch granules have a stable semi-crystalline structure, and their swelling in water is reversible at a lower gelatinisation temperature. The water absorption is usually less than 40%. When the suspension temperature of the starch granule is higher than that of water, the starch granule will lose birefringence and crystallinity, and swelling occurs at the same time. This is irreversible and called gelatinisation (Alcázar-Alay & Meireles, 2015). Starch gelatinisation is the destruction of the molecular sequence in starch granules. It is accompanied by irreversible characteristic changes such as particle swelling, microcrystalline melting, loss of refractive index difference, viscosity development, and solubilities. The point, and extent, of initial gelatinisation can be controlled by starch concentration, method of observation, particle type, and heterogeneity between observed particles. Starch swelling behaviour not only depends on starch origin but also depends on amylose content (Cornejo-Ramírez *et al.*, 2018). Jenkins (1994) stated that gelatinisation in excess water is mainly a process driven by swelling. This swelling causes the microcrystals in the unstable amylopectin crystal sheet to be torn apart (the smaller ones are destroyed first). This process occurs rapidly for an individual microcrystal but varies widely for the entire particle. The same mechanism occurs under water restriction. However, there is not enough water for gelatinisation to be completed. At higher temperatures, the remaining microcrystals melt. These gelatinisation and swelling properties are partly controlled by the molecular structure of amylopectin (unit chain length, degree of branching, molecular weight, and polydispersity), starch composition (amylose to amylopectin ratio, lipid complex amylose, and phosphorus content), and granular structure (crystallization to amorphous ratio) (Tester, 1997).

When starch is heated, the suspension turns into swelling particles, and then some of the particles gradually disintegrate. Finally, the particles release amylose and amylopectin, and the flow behaviour of granular slurry will change significantly. The cooked product is called a starch paste. Usually, the starch paste is a two-phase system consisting of the dispersed phase of the swelling particles and the continuous phase of the leached amylose. It can be thought of as a polymer composite in which swollen particles are embedded and strengthen a constant matrix of tangling amylose molecules (Ring, 1985).

In food processing, the starch suspension is subjected to the combined action of high temperature and high shear rate, which will affect the physical properties of starch and the final characteristics of the product. Depending on the starch concentration, the final structure of the starchy product will be a thickened solution or a gelatinised composition if the amylose phase is continuous, aggregation with the linear chain segment of amylopectin during cooling results in the formation of a strong gel.

The use of potato starch in food and non-food products has increased dramatically in the past few decades (Waterschoot, Gomand, Fierens, & Delcour, 2015). Potato starch has a high viscosity and low gelatinisation temperature, this suggests that potato starch is easier to gelatinise than other starches and produces a sticky paste that is more brittle.

The gelatinisation and pasting profiles of flour-water or starch-water mixtures are commonly monitored using a Rapid Visco Analyzer (RVA), which is a heating and cooling viscometer to measure the resistance of a sample to controlled shear. A typical RVA profile of potato starch gelatinisation is illustrated in Figure 2.4 and shows that the viscosity increases to a maximum, followed by a decrease to a minimum value as the granules rupture (breakdown). Then the viscosity rises from the minimum to a final value, which is referred to as the setback, and the value of setback is related to the amylose content of the potato starch and the ease with which the starch is retrograded (Copeland, Blazek, Salman, & Tang, 2009). Therefore, the RVA provides a convenient way of investigating the rheology of starch products.

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Figure 2.4 Typical RVA profile of potato starch (Higley, Love, Price, Nelson, & Huber, 2003)

The gelatinisation characteristics of tuber starch are listed in Table 2.4. The gelatinisation curves of these starches have been measured at different concentrations. Obviously, potato starch has a higher gelatinisation temperature and thermal stability.

Table 2.4 General pasting characteristics of tuber and root starches

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Adapted from (Hoover, 2001)

The gelatinisation of starch is affected by amylose and lipid content and amylopectin length distribution. Amylopectin contributes to the swelling and gelatinisation of starch granules, while amylose and lipids inhibit swelling (Tester & Morrison, 1990). The chain length of amylopectin and the molecular size of amylose also have a synergistic effect on the viscosity of the starch pasting (Jane & Chen, 1992).

2.4.3 Retrogradation

Following gelatinisation, a process called retrogradation generally occurs during storage. During this process, starch pastes may become cloudy and eventually deposit an insoluble white precipitate. This is caused by the recrystallization of starch molecules, amylose and amylopectin reassociation and reform into ordered structures (Wang, Li, Copeland, Niu, & Wang, 2015). Retrogradation is an ongoing process, amylose is considered to be primarily responsible for the short-term retrogradation, due to dissolved amylose molecules are redirected in parallel directions. The long-term retrogradation is represented by the slow recrystallization of the outer branches of amylopectin (Leloup, Colonna, Ring, Roberts, & Wells, 1992; Shi & Seib, 1992). Figure 2.5 shows the changes in the starch and water mixture during heating, cooling and storage.

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Figure 2.5 The changes in the starch and water mixture during heating, cooling and storage.

Changes in the starch - water mixture during heating, cooling, and storage. (I) Native starch granules; (II) Gelatinisation during heating; (III) retrogradation during cooling and storage (Goesaert *et al.*, 2005).

Starch retrogradation is generally considered to have a negative effect on product quality because it plays a major role in the staling of bread and other starch-rich foods, which can lead to shorter shelf life and lower consumer acceptance, as well as large amounts of waste, thus posing a major challenge to food processors (Chandrasekaran, 2012). However, due to structural, mechanical, and sensory changes, starch retrogradation is beneficial for some food products, such as breakfast cereals, semi-cooked rice, dehydrated mashed potatoes, and Chinese vermicelli (Karim, Norziah, & Seow, 2000). In addition, enzyme digestion of starch retrogradation is slow, moderated release of glucose into the blood stream, and the moderate version of glucose release into the bloodstream brings health benefits (Wang & Copeland, 2013).

Starch retrogradation is a complex physicochemical process. Differential scanning calorimetry (DSC) has been proven to be an extremely valuable and sensitive tool to characterize starch retrogradation. In the case of starch retrogradation, DSC endothermic provides quantitative measurements of enthalpy and transition temperature for the melting of recrystallized amylopectin (Karim *et al.*, 2000). Starch retrogradation has been shown to be affected by many factors. Water content, starch source, and storage conditions significantly affect the retrogradation of starch. The presence of food components (e.g., lipids, carbohydrates, salts, proteins, or peptides) has also been appeared to play an important role in restraining the rate of starch retrogradation (Wang *et al.*, 2015).

Water plays an essential role in the gelatinisation and retrogradation of starch in the processing and storage of foods. Wang and Copeland (2013) reviewed the effect of water on starch gelatinisation. The rate and degree of starch regrowth also depended on the water content. Amylose content affected the impact of water content on the retrogradation of starch, and amylose content will also affect the crystallization of amylopectin. When the water content was lower than 20% or higher than 90%, DSC could not observe the coagulation of corn and wheat starch. When water content was reduced to 80%, retrogradation occurred in non-waxy corn starch, but no retrogradation was found in waxy starch. When the water content was further reduced to 70%, both waxy and non-waxy starches had retrogradation, and the enthalpy change of the former was small, indicating that the retrogradation of starch was promoted in the presence of amylose. When the water content is 60%, amylose content does not affect starch degradation (Zhou, Wang, Yoo, & Lim, 2011).

Temperature and storage time are the main factors to determine the degree of starch retrogradation. Typically, the initial degradation is rapid and then slow. At constant temperature, the initial temperature and enthalpy change of degradation starch molecules melting increased with the increase of storage time, but the temperature hardly changed (Fu, Wang, Li, Zhou, & Adhikari, 2013; Xie, Hu, Jin, Xu, & Chen, 2014). The hardness and elasticity of denatured starch gels increase during initial storage at a constant temperature but vary only slightly during more extended storage (Ambigaipalan, Hoover, Donner, & Liu, 2013; Zhang, Hu, Xu, Jin, & Tian, 2011). The most common temperature conditions for studying starch retrogradation are thermostatically stored at 4, 25, or 30°C, or temperature cycles between 4 and 25°C (or 30°C).

Due to the highly complex molecular structure of intact granules, natural starch is slowly digested by enzymes (Wang & Copeland, 2013). Processing or cooking destroys the ordered arrangement of granular starch, resulting in increased sensitivity of starch to enzyme digestion. Subsequent cooling and storage lead to condensation, in which the starch regains an ordered structure and is more resistant to digestion by enzymes (Zhou & Lim, 2012). The digestibility of degraded starch depends largely on storage time and temperature. At a constant temperature, the shorter storage time causes the rapid retrogradation of amylose molecules, which is responsible for the initial decrease in the digestibility of retrogradation starch. A longer storage time contributes less to the reduction of the digestibility of amylopectin due to the slow regeneration rate of amylopectin molecules (Chung, Lim, & Lim, 2006). Compared with gelatinised starch, the content of RDS decreased, and that of SDS has been shown to increase due to the reduced digestibility of recovering starch. However, the content of antagonistic starch (RS) was shown not to be affected (Fredriksson *et al.*, 2000; Zhou & Lim, 2012).

Gelatinisation and retrogradation are the key functional properties of starch which determine the quality and nutritional value of starchy food. Starch accounts for more than 50% of average calorie intake in western countries and 90% in developing countries. How we digest starch, one of the most important carbohydrates in many foods, has a major impact on health (Wang *et al.*, 2015). The production of starch with slow digestion characteristics is an important goal of the food industry.

2.5 Potato and Derivatives in Food Application

Staple food is a food that is eaten routinely and, in such amounts, that it constitutes a regular quantity of a standard diet in a given population, supplying a significant division of the needs for energy-rich materials and for the most part a significant proportion of the intake of other nutrients as well. The staple food of a particular society may be eaten as frequently as each day or each supper, and most people live on a diet based on just a small number of staple foods. Staple foods change from place to place, but are accessible foods that supply natural macronutrients required for survival and wellbeing: carbohydrates, proteins, and fats. Typical examples of staple foods include tuber or root crops, grains, legumes, and other seeds. As the staple food, potato is mainly consumed as fresh food. Processed products account for less than 10% of the total potato output, and the processed products are mainly starch, modified starch, potato chips, and fried potato chips (Zaheer & Akhtar, 2016). The single product and low nutritional value greatly limit potato consumption. Table 2.5 listed the main processed potato products.

Starch is the main carbohydrate in potatoes and an important agricultural commodity with many food and non-food uses. In the food industry, potato starch can be used in a variety of products as a food component or industrial raw material, starch plays an important role in human nutrition by providing metabolic energy that enables the body to function. It is the basic energy source for a large part of the world's population (Lisinska & Leszczynski, 1989). Potatoes contain up to 75% RS in the uncooked state, but in their original or natural state, potato starch is rarely eaten directly. When cooked, RS is reduced to about 5-10% (Englyst, Kingman, & Cummings, 1992). However, some RS can be recovered during cooling (that is, boiled potatoes are refrigerated), which is conducive to retrogradation and leads to a lower GI (Dupuis, Lu, Yada, & Liu, 2016).

Table 2.5 The main processed potato products

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Adapted from (Camire *et al.*, 2009)

However, some studies have shown that extraction of starch, as the main form of potato processing, not only causes the loss of nutrients in potato, such as vitamins, proteins and dietary fibre, but also causes a certain degree of pollution to the environment (Pu *et al.*, 2017; Vikelouda & Kiosseoglou, 2004; Waglay *et al.*, 2014). Compared with potato starch, potato flour has a wider range of nutrients and also retains a better flavour and taste in terms of consumer appreciation (Rytel, 2012). Potato flour is widely used because of its rich nutrients and good taste. It is processed into various kinds of food, for instance potato flour is used instead of wheat flour in baking, extruded snacks and biscuits (Anupama & Kalpana, 2003; Nemar *et al.*, 2015; Singh, Kaur, McCarthy, Moughan, & Singh, 2009). Potato products also include potato bread, potato noodles, potato cooked corn cake, mashed potatoes, potato chips and potato cakes (Drakos *et al.*, 2017; Huang, 2014; Zhu, 2014).

Ijah, Auta, Aduloju, and Aransiola (2014) mixed potato flour with wheat flour at substitution levels of 0% to 10% to make bread. The microbial and nutritional quality of normal bread and experimental breads were compared. The results showed that adding potato flour to wheat flour improved the nutritional value of bread. Sensory assessments indicated that in commercial bread production, consumers could accept bread with added potato flour. Similarly, Liu *et al.* (2017) studied the nutritional quality of steamed and baked breads containing 35 percent potato powder from four potato varieties. Compared with traditional wheat varieties, potato-wheat buns and bread contained higher dietary fibre (1.87 to 2.21 times), potassium (2.68 to 3.36 times), vitamin C (28.56 to 50.21 times), and total polyphenols (1.90 to 3.33 times) and higher antioxidant activity (1.23 to 1.54 times). The researchers estimated GI of potato-wheat bread ranged from 61.20 to 67.36, lower than that of steamed bread (70.22) and baked bread (70.62).

However, due to the lack of gluten protein, it is difficult to prepare potato pasta and noodles from potato alone. It is feasible to process potato noodles with whole potato powder and wheat flour as the main raw materials (Wei *et al.*, 2016). Based on the three factors of potato powder content, salt content, and water content, an orthogonal experiment was carried out. Sensory assessment of the rate of breakage and loss of cooked noodles allows the selection of the best ingredients. The orthogonal results showed that the optimum formula of potato bread are 10% whole potato powder, 1.5% salt, and 42% water (Wang, Huang Zhang, Guo & Pu, 2017). Pu *et al.* (2017) studied the effect of the ratio of potato flour to wheat flour on the mixing characteristics of the dough and the quality of the noodles. Their results showed that potato flour, instead of wheat flour, weakened dough strength but improved the resistance to degradation. The texture, cooking, sensory properties, and microstructure of the noodle samples were also evaluated. The results showed that adhesion, elasticity, and sensory evaluation continued to decrease with potato inclusion. However, the hardness, cooking yield, and optimal cooking time of the samples with potato powder content showed significant differences to the control samples. Environmental scanning electron microscopy (ESEM) confirmed the change of noodle microstructure, and the addition of potato flour affected the formation of the gluten network. Generally, noodles with less than 40% potato flour content were deemed acceptable.

At present, the noodles on the market use wheat flour as the primary raw material, but as a result of consumer demand for nutritional staple food higher and higher, additional cereal grains or other vegetables are added and these new nutrition noodles made by popular with more and more consumers, a trend to the progress of the noodles. Noodles made from potato flour and wheat flour differ from traditional wheat noodles. There is no gluten protein in potato powder, and the addition of potato flour results in the deterioration of noodle texture characteristics. We are faced with a significant problem, namely, how to improve the quality of potato noodles. At present, there are few reports on the effects of potato flour on the rheological properties of dough, texture, and nutritional properties of noodles.

2.6 Pasta and Noodle Production

Pasta and noodles are staple foods in numerous nations. They are different in many ways, mainly due to the different "raw materials" used for production. Pasta is made from durum wheat flour, while noodles are either made with regular wheat flour (and salt), or with starches from a range of plant sources. In the latter case, they are called starch noodles (Aravind, Sissons, Egan, & Fellows, 2012).

Traditionally from Italy, pasta has become a worldwide consumer product thanks to its ease of transport, ease of handling, ease of cooking, and long shelf life (Rayas-Duarte, Mock, & Satterlee, 1996). Pasta is usually made by extrusion. In this process, the flour is mixed with water (usually about 30-35% water) to form a dough, which passes through a die and then dries (Torres, Frías, Granito, & Vidal-Valverde, 2006; Zhao, Manthey, Chang, Hou, & Yuan, 2005). In the process of pasta production, wheat is used to produce pasta flour due to its protein composition, which forms a very strong viscoelastic network. Among wheat, durum wheat flour is considered the best material (Borneo & Aguirre, 2008; Mercier, Villeneuve, Mondor, & Des Marchais, 2011). The proteins in durum wheat semolina are made up of albumin, globulin, gluten, and gliadin. The latter two can interact with each other, and interact with other components, to form intramolecular and intermolecular disulphide bonds to build a three-dimensional viscoelastic gluten network (Martínez-Villaluenga, Torres, Frías, & Vidal-Valverde, 2010).

In addition to controlling viscoelasticity, protein content and composition also determine the quality of the flour, which in turn determines the quality of the pasta (e.g., firmness and flexibility) (Martínez-Villaluenga *et al.*, 2010). The best raw material for making pasta is durum wheat semolina, which is high in protein and leads to the formation of a dense gluten network. This viscoelastic network limits starch expansion and maintains structural surfaces during cooking, thereby preventing cooking losses (Petitot *et al.*, 2010).

Owing to this research being focused on the application of potato flour in producing pasta, more research reviews on pasta and noodle production were listed in the following. Noodles can be classified into Chinese type wheat noodles, Japanese type wheat noodles, buckwheat noodles, Korean type noodles (Naengmyeon noodles), rice noodles, starch noodles, and different pasta made from a variety of materials. Starch-based noodles are one of the most popular foods in oriental countries, and potato starch plays an important role in the production of starch noodles (LaBell, 1990). Compared to wheat starch, potato starch has been reported to present lower phospholipids and to generate a starch paste with higher transmittance as well as large granule size, which has been used to produce several types of noodles (Noda *et al.*, 2006; Singh, Singh, Kaur, Singh Sodhi, & Singh Gill, 2003). After cooking, potato noodles have been reported to have a clear appearance and a smooth texture (Sandhu & Kaur, 2010). Additionally, the viscosity and pasting properties of potato noodles were reported by Mitch (1984) as being higher than wheat noodles.

Durum wheat semolina is the most commonly used raw material for producing high quality pasta in the western countries (Foschia, *et al.,* 2015a; Foschia, *et al.,* 2015b), which is known to be a low to medium GI food (Granfeldt & Björck, 1991). The physicochemical and sensory properties of potato starch/flour in pasta have been studied to reveal the potential application of potato starch in producing pasta (Alessandrini, Balestra, Romani, Rocculi, & Rosa, 2010). Over the years, research on noodles/pasta manufactured from wheat flour and potato starch mixes have focused on their product quality and properties such as their physicochemical, gel textural, pasting properties (Zaidul, *et al.*, 2008; Zaidul, Norulaini, Omar, Yamauchi, & Noda, 2007; Zaidul, Yamauchi, Matsuura-Endo, Takigawa,

& Noda, 2008). However, little research has been carried out on the thermal properties and digestion rate of potato-based products. Additionally, the importance of developing low GI potato-based pasta is possibly currently underestimated.

The quality of pasta and noodles is defined by their cooking quality (cooking loss (CL) and swelling index (SI)) as well as their texture and other sensory properties (Brennan, Kuri, & Tudorica, 2004). Cooking loss (CL) refers to the amount of material separated from the product into the cooking water. In contrast, the swelling index refers to the amount of water absorbed by the pasta and noodles. Whether it is pasta or starchy, high quality products should have low cooking losses. In terms of processing properties, texture, and sensory properties, the starch noodles shall have a low viscosity to facilitate the separation into strands during the drying process. Starch noodles are generally translucent and elastic (Inglett, Peterson, Carriere, & Maneepun, 2005). High quality pasta is defined as having a low thickness and high firmness. The concentration of starch in pasta products may damage product quality characteristics such as cooking quality, texture, and sensory characteristics (Izydorczyk, Lagasse, Hatcher, Dexter, & Rossnagel, 2005; Lucisano, Casiraghi, & Barbieri, 1984). The addition of flour other than wheat increases cooking losses, reduces dough firmness and increases dough stickiness, and generally makes floured products less acceptable than pasta (Chillo *et al.*, 2009). These negative effects are associated with network dilution as wheat flour or starch is replaced by vegetable/bean flour that does not contain the protein that forms the network (Sabo & Hardi, 2007). In summary, these components and their interactions determine the microstructure of pasta products and, to a large extent, determine the quality characteristics of pasta products.

2.7 Soy Protein Fortification of Food

Starch and protein are the two main components in the food matrix, which are the specific and required texture formation products of food structure formation (Zhang, Mu, & Sun, 2016). Soy protein is a good source of plant protein and the 8 amino acids which it contains can fulfil some of the requirements of the human body. There are lots of benefits associated with consuming soy foods such as lowering plasma cholesterol, preventing cancer, diabetes, obesity, and protecting against bowel and kidney diseases (Messina, 1999).

Soy ingredients promote retention of water and flavour, contribute to emulsification, and enhance the texture of many foods, from various meats to peanut butter, frozen desserts, and even cheese. Soy protein is easily digested and of the same quality as the protein in milk, meat, and eggs. Soy protein is acceptable in almost all cholesterol-free and lactose-free diets. The supplement industry, capsule and tablet industry, and the functional food industry are increasingly using the commercial components of soy to make bars, bread, crackers, breakfast cereals, dairy products and beverages (Rueda, Kil-Chang, & Bustos, 2004). Compared with other protein commodities, soybean protein products are composed of high quality protein table 2.6.

Table 2.6 Protein and calorie contents of some commodities

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Adapted from (Singh, Kumar, Sabapathy, & Bawa, 2008)

Soy protein contains all the essential amino acids for human nutrition (Table 2.7). Except for sulphur-containing amino acids (such as methionine), the amino acid composition of soy protein is similar to the amino acid pattern of high-quality animal protein sources (Wolf, 1970). Digestibility studies in animals and humans have shown that the digestibility of soy protein is comparable to that of other high-quality proteins such as meat, milk, fish, and eggs (Öste, 1991).

Table 2.7 Essential amino acid content of soybean proteins

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Adapted from (Lönnerdal, 1994)

The successful use of soy protein in conventional foods depends on the preparation of the product in a manner that preserves the traditional characteristics of the product. When plant proteins replace animal proteins, the characteristics and quality of traditional foods must remain unchanged (Berry, 1998).

Owing to the increase of nutrition value (higher mineral and protein content) and improved sensory characteristics, soy flour is used for fortification of foods more often than milk proteins for instance, and the potential of incorporating soybean into noodles was reported (Kaur, Sharma, Nagi, & Ranote, 2013; Li, Zhu, Guo, Brijs, & Zhou, 2014). The addition of soy ingredients has been shown to increase the protein proportion of food products and improve the quality and nutrition of wheat flour-based noodles. Therefore, soy protein is widely used for fortification in noodle production and is becoming an important part of the global diet (Kaur *et al.*, 2013; Li *et al.*, 2014). In pasta products, a variety of macaroni products are fortified with soy protein to increase their nutritional value. Soy protein products increase the absorption of pasta dough and increase hardness, which has particular advantages for long-cooked pasta (Tsen, Farrell, Hoover, & Crowley, 1975). Soy protein isolates usually produce the lightest colour. Limroongreungrat and Huang (2007) prepared the pasta product from sweet potato with defatted soybean flour (DSF) and soybean protein concentrate (SPC), and then adding DSF and SPC at 0, 15, 30 and 45 g /100 g increased the brightness (L*) from 40.6 to 48.7, and decreased the reversion (a*) from 21.6 to 15.2. The replacement of DSF and SPC reduces the hardness from 1.8n to 0.4n, the cohesion from 0.6 to 0.5, and the elasticity from 1.2 to 1.1mm.

As consumers learn more about nutrition, food manufacturers have adapted their recipes to meet the changing needs of the market. With the improvement of peoples' standard of living, high-protein-low-carbohydrate foods are becoming a major focus of researchers in food science as these diets are associated with promoting, and maintaining, good health (Cho & Rizvi, 2010; Yong, Chan, García, & Sopade, 2011). In the processing of protein-starch systems, starch and protein can be gelatinised and denatured, respectively, so it is critical to understand such properties as the pasting, gelatinisation, textural and physiochemical properties of protein-starch complexes, which will affect the digestibility of starch, protein and their mixtures (Yong *et al.*, 2011).

As mentioned above, there are many potential advantages in soy protein fortification in producing noodles. However, how soy protein affects the GI of starch-based foods has not been well investigated. It is essential to understand the actual mechanism of interactions and fundamental aspects of starch and protein (Kumar, Brennan, Mason, Zheng, & Brennan, 2016). Potato flour is used in combination with other protein-rich sources to help increase the protein content of potato staples. Soy flour with 43% protein and 20% fat, is an ideal source of cheap calories and protein (Gopalan, Rama Sastri, & Balasubramanian, 2007).

This thesis aimed to determine the potato flour replace for wheat flour in the preparation of new types of pasta to meet the requirement of people for nutritional staple foods.

Firstly, we examined the physical chemical characteristics, nutritional analysis, pasting and digestion behaviour of two variety of potatoes flour (Agria and Nadine) used in three different ways to produce. Secondly, investigated starch-protein interactions on quality and nutritional properties in manufactured pasta with different proportions of potato flour substitute. Finally, high protein pasta, with low starch digestibility, was developed from two different potato genotypes, using soy protein sources. This is of considerable significance to the further development of the potato processing industry.

Chapter 3

Materials and Methods

Overview

This Chapter covers the explanation and information about the materials used, and suppliers for all experimental procedures. An overview of the experimental design is given in Figure 3.1.

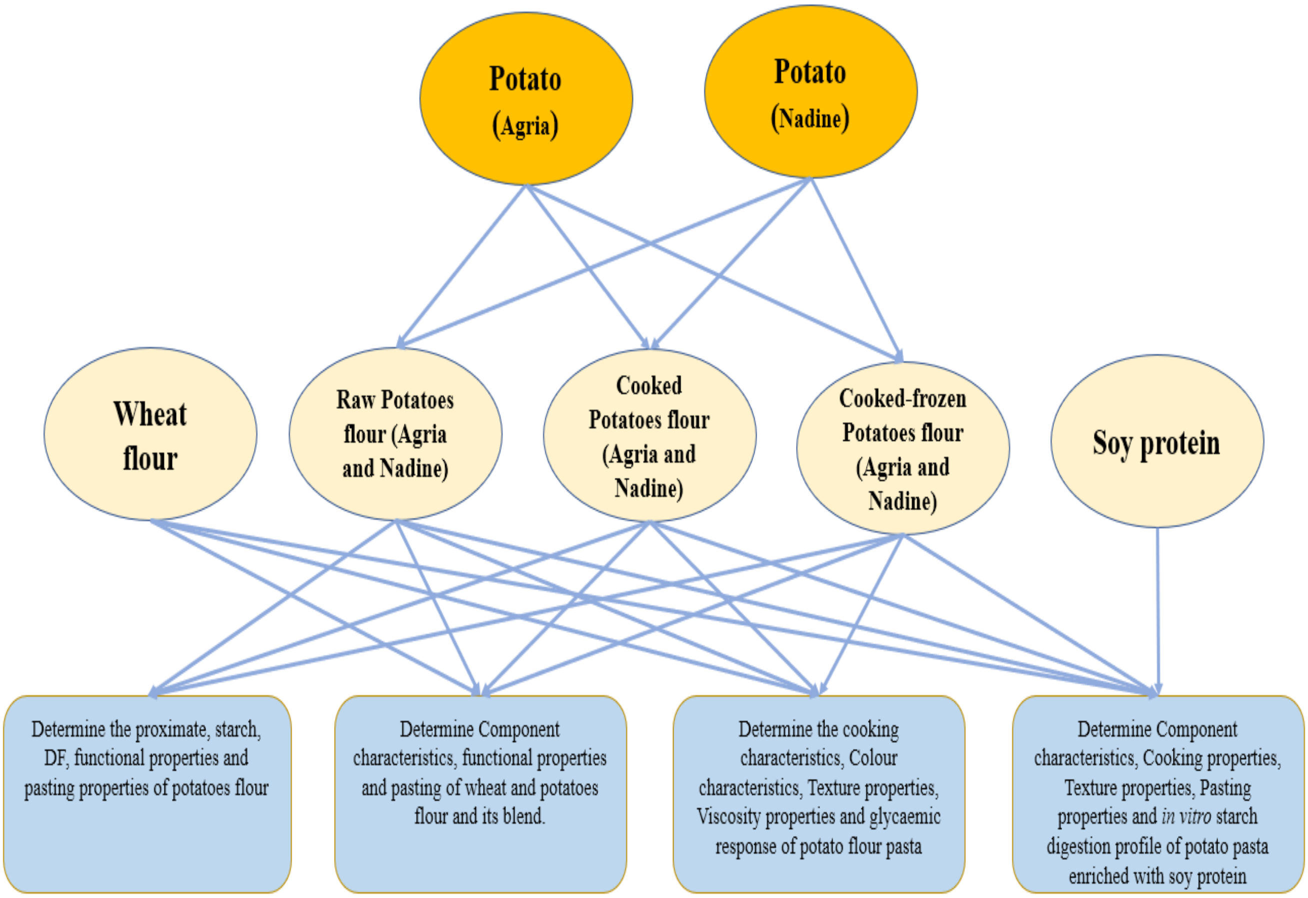


Figure 3.1 Experimental design of the thesis experiments

3.1 Materials

3.1.1 Potato Flour Pre-treatment

Two different commercially released cultivars of potato (Agria and Nadine) were purchased in local supermarket (New World) in Christchurch in New Zealand (2017 harvest). Potato tubers were used as a raw material for processing of potato and starch flour (Figure 3.2).

The peeled potato were sliced into thin slices of 2-3 mm thickness using scale slicer and then dipped in potassium metabisulfite solution (30 g $100L^{-1}$) for 10-15 s. Raw Agria potato Flour (RAF) and Raw Nadine flour (RNF) were prepared by the method of Singh *et al.* (2009) with some modification. Cooked potato flour (CAF, CNF) were prepared following the formulation of Liu *et al.* (2017) with some modification. The slices were boiled at 100℃ for 30 mins, then cooled at 25℃, cooked-frozen potato flour (CFAF, CFNF) were prepared by the method of Yu, Mu, Zhang, Ma, and Zhao (2015) with some modification, the slices were boiled at 100℃ for 30 mins, cooled in air-tight plastic containers at room temperature, and finally frozen at -18℃ for 12 hours. All the processed slices (thaw frozen potato slices at room temperature) were dried at 45 ± 2℃ for 24 hours in an oven, milled with a food liquidizer (Breville, platinum, Sydney, Australia) and sieved through a 100 μm screen to obtain flour of uniform particle size. After measuring the final weight, the cooked-frozen potato flour was stored at 4 ℃ in air-tight plastic containers until used, the raw and the cooked flour were stored at room temperature in air-tight plastic containers until further use.

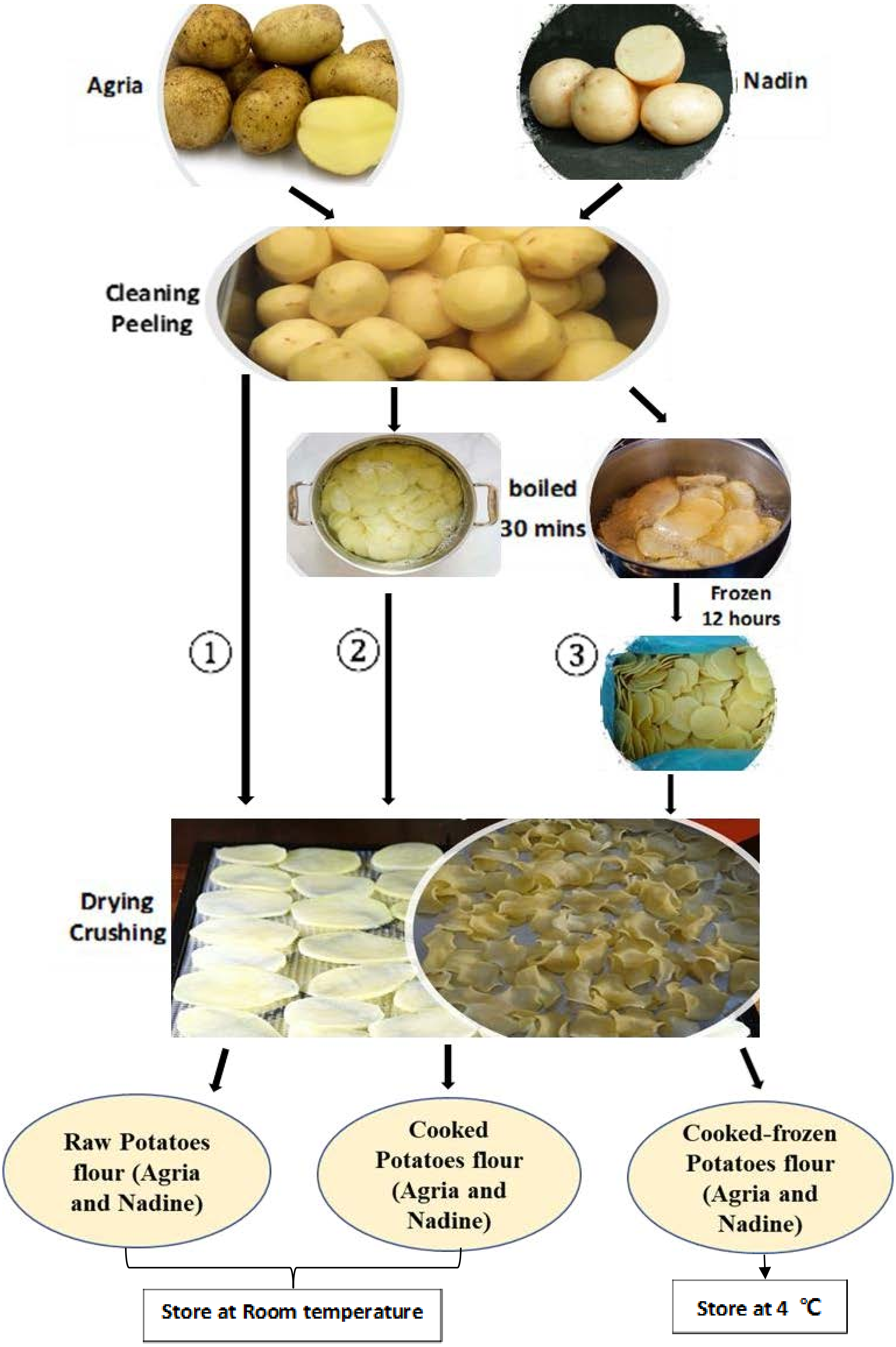


Figure 3.2 **The potato flour production process.**

3.1.2 Other Materials

Durum semolina was purchased from Sun Valley Foods Limited, Auckland, New Zealand. Soy protein isolate with 91% of protein content was purchased from Bulk Powder Limited, Braeside, Australia.

3.1.3 Preparation of Blended Samples

Wheat flour, and the six types of potato flour, were used in the investigation. Wheat flour was blended with potato flour at 10-50%, and a control samples were prepared using 100 % wheat semolina and 100 % potato flour, as shown in Table 3.1.

Table 3.1 Mixing ratios (%) of wheat flour and six types of potato flour

Sample	Mixing ratio
Wheat: Potato	10: 0 (control wheat)
Wheat: Potato	0: 10 (control potato)
Wheat: 10% Potato	9:1 (10% RAF, 10%CAF, 10%CFAF, 10%RNF, 10%CNF, 10%CFNF)
Wheat: 20% Potato	8:2 (20% RAF, 20%CAF, 20%CFAF, 20%RNF, 20%CNF, 20%CFNF)
Wheat: 30% Potato	7:3 (30% RAF, 30%CAF, 30%CFAF, 30%RNF, 30%CNF, 30%CFNF)
Wheat: 40% Potato	6:4 (40% RAF, 40%CAF, 40%CFAF, 40%RNF, 40%CNF, 40%CFNF)
Wheat: 50% Potato	5:5 (50% RAF, 50%CAF, 50%CFAF, 50%RNF, 50%CNF, 50%CFNF)

RAF, Raw Agria potato Flour; CAF, Cooked Agria potato flour; CFAF, Cooked-Frozen Agria potato flour; RNF, Raw Nadine flour; CNF, Cooked Nadine potato flour; CFNF, Cooked-Frozen Nadine potato flour.

3.1.4 Preparation of Pasta

Pasta extrusion was conducted using a Fimar Villa Verucchio pasta machine Model Number MPF15N235M, (Rimini, Italy). The pasta making machine consisted of a stainless steel basin, with an agitator (kneader) to facilitate the appropriate mixing of material. A bronze alloy shaft was fitted at the bottom of the basin for conveying material towards the die. Each blend, 500 g dry ingredients and

32.5 g per 100 g water (tap water, 41 °C), was mixed for 20 min according to the manufacturer's guidelines. The pasta samples were kept in zip lock bags and stored in a freezer at -18 °C until use.

3.1.4.1 Preparation of potato flour pasta

Each of the six types of potato flour were used to replace durum wheat at 10%-50%, and a control sample was prepared using 100 % wheat semolina, as shown in Table 3.2

Table 3.2 Mixing ratios (%) of wheat flour and six types of potato flour in potato pasta

Sample	Mixing ratio
Wheat: Potato	10: 0 (control wheat)
Wheat: 10% Potato	9:1 (10% RAF, 10%CAF, 10%CFAF, 10%RNF, 10%CNF, 10%CFNF)
Wheat: 20% Potato	8:2 (20% RAF, 20%CAF, 20%CFAF, 20%RNF, 20%CNF, 20%CFNF)
Wheat: 30% Potato	7:3 (30% RAF, 30%CAF, 30%CFAF, 30%RNF, 30%CNF, 30%CFNF)
Wheat: 40% Potato	6:4 (40% RAF, 40%CAF, 40%CFAF, 40%RNF, 40%CNF, 40%CFNF)
Wheat: 50% Potato	5:5 (50% RAF, 50%CAF, 50%CFAF, 50%RNF, 50%CNF, 50%CFNF)

RAF, Raw Agria potato Flour; CAF, Cooked Agria potato flour; CFAF, Cooked-Frozen Agria potato flour; RNF, Raw Nadine flour; CNF, Cooked Nadine potato flour; CFNF, Cooked-Frozen Nadine potato flour.

3.1.4.2 Preparation of potato pasta enriched with soy protein

The combination of ingredients to make the potato pasta enriched with soy protein pasta is shown in Table 3.3.

Table 3.3 Combination of potato pasta enriched with soy protein

Sample	Mixing ratio
Wheat-30% Potato: Soy protein	10: 0 (control 30% RAF, 30%CAF, 30%CFAF, 30%RNF, 30%CNF, 30%CFNF)
Wheat-30% Potato: Soy protein	98: 2 (30% RAF+2%S, 30%CAF+2%S, 30%CFAF+2%S, 30%RNF+2%S, 30%CNF+2%S, 30%CFNF+2%S)
Wheat-30% Potato: Soy protein	96: 4 (30% RAF+4%S, 30%CAF+4%S, 30%CFAF+4%S, 30%RNF+4%S, 30%CNF+4%S, 30%CFNF+4%S)
Wheat: 30% Potato	94: 6 (30% RAF+6%S, 30%CAF+6%S, 30%CFAF+6%S, 30%RNF+6%S, 30%CNF+6%S, 30%CFNF+6%S)

RAF, Raw Agria potato Flour; CAF, Cooked Agria potato flour; CFAF, Cooked-Frozen Agria potato flour; RNF, Raw Nadine flour; CNF, Cooked Nadine potato flour; CFNF, Cooked-Frozen Nadine potato flour.

3.2 Physical Analysis

3.2.1 Dry Matter Content (%) and Starch Content (%) of Raw Potato

The dry matter (DM) content (%) and starch content (%) of raw potato were measured according to the methods described by Bu-Contreras and Rao (2001) as modified by Singh *et al.* (2009). DM (%) was assayed by drying weighed potato slices in aluminium containers in the oven (105 ± 2℃,24 hours) until constant weight. The starch content (%) of raw potato was determined using the percentage of DM (%) in the potato, was calculated using the following formula (AOAC, 1980).

$$\text{Starch content (\%) of raw potato} = 17.55 + (0.891 \times tuber\ dry\ weight\% - 24.182) \quad (1)$$

3.2.2 Percentage Yield of Potato Flour

The yield of potato flour from the raw potato tubers was calculated using the following equations, (Kulkarni, Govinden, & Kulkarni, 1996)

Yield (%) = *(weight of potato flour/ weight of peeled whole potato)* $\times$ 100

3.2.3 Measurement of Moisture Content

The moisture content of the pasta samples was determined using the method given by Approved Methods of the AACC (2010). A clean coded aluminium cup was first dried in an oven at 105 °C for 30 min, cooled in a desiccator and weighed. A ground sample (5 g) was placed in the cup and placed in an oven at 105 °C overnight. The cup was allowed to cool in a desiccator.

The weight of the cup plus contents after drying was recorded and moisture content calculated according to the equation below:

$$\text{Moisture content (\%)} = \frac{Weight\ of\ fresh\ sample - Weight\ of\ the\ dried\ sample}{Weight\ of\ the\ sample}$$

3.2.4 Fat Determination

Crude fat was determined using a BUCHI Soxhlet Extraction Unit E-816HE (De Castro & Priego-Capote, 2010). Samples (1 g) were weighed into separate thimbles to perform the extraction. Petroleum ether was then added to the glass tubes and the tubes were suspended in the glass tube with a holder. The principle was that a dried ground sample was extracted with petroleum spirit; this dissolves fat, oils, pigments and other fat-soluble substances. The petroleum spirit was then evaporated from the fat solution by boiling the solvent. After one hour the glass tubes were placed in a hot air oven (105 °C) for 20 mins. The samples were then cooled for 10 min before weighing. The resulting residue was weighed and referred to as either extract or crude fat.

3.2.5 Phosphorous Content of Potato

The phosphorous of potato flour was estimated as described by Noda *et al.* (2004). The samples (0.2g) were placed in a miniature Kjeldahl flask and heated with 2 ml HNO_3 until brown smoke stopped being emitted. The solution was then cooled; 1.5 ml of 60% perchloric acid and 1.5 ml of HNO_3 were added to the mixture, and the mixture was heated. When white smoke was produced, the solution was cooled. Then, 3 ml of distilled water was added, and the mixture was heated. After heating, the solution was made up to 10 ml with distilled water. The Vanado - molybdate method was used to measure the digestive solutions of phosphorus content of inorganic phosphorus, and to calculate the phosphorus content of the sample. For analysis, 2 ml of digestive juice was mixed with 3 ml of distilled water, 0.5 ml of 60% perchloric acid, 1.5 ml of 20 mM vanadium solution with 2.4% perchloric acid and 3.0 ml of 3.53% ammonium molybdate solution. The solution was left for 30 minutes, and the absorbance was read at 420nm. Calculation of the Phosphorous Content (%):

$$\text{Phosphorous Content (\%)} = \left(\frac{0.005 \times \text{A}}{\text{M} \times 1000 \times 2/250}\right) \times 100$$

A: the absorbance was read at 420nm.   M: weight of sample.

3.2.6 Protein and Ash Content Determination

The protein contents of samples were determined using the conversion factors of 5.7 (AOAC 992.23) and Mariotti, Tomé, and Mirand (2008). Samples (600 mg) were weighed in triplicate and loaded individually into the DUMAS machine to measure the total nitrogen. The nitrogen content was determined using an Elemental analyser Model Vario MAX CN Hanau, Germany. The instrument works according to the principle of catalytic tube combustion under oxygen and at a high temperature. The combustion gases are separated from the foreign gases. Carbon and N were then separated from each other by specific adsorption columns and then detected in succession using a thermal conductivity detector. The carrier gas was helium.

The protein percentage (dry basis (DB)) was calculated by the following formula: % protein = N × 5.7. Where, 5.7 is the correction factor used to convert the nitrogen content of pasta and bread into protein content (Leser, 2013).

Ash content (g/100 g DB) was determined by weighing samples before and after heat treatment (550 °C for 12 h). The residue was incinerated for 5 h at 525 ℃. The container of ash was cooled indicators and weighed to the nearest 0.1 mg.

Calculation of the ash weight:

$$Ash\ (g) = weight\ (obtained) - weight\ of\ crucible - weight\ of\ \ Celite$$

3.2.7 Determination of Total Starch Content.

The total starch content was determined by using the Total Starch Assay kit (Megazyme, Ireland) based on AOAC Official Method 996.11(AOAC, 2000) as illustrated in Figure 3.3.

The sample (0.1 g) and 5.0 ml 80% EtOH were placed in a centrifugal tube and then incubated in a water bath with a water temperature of 80-85 ℃ for 5 min. The samples were stirred, and 5.0 ml 80% EtOH was added. The test tube was placed in a bench centrifuge (ROTINA 380, Hettich LAB TECHNOLOGY, Tuttlingen, Germany) and centrifuged at 3000 RPM for 10 minutes before the supernatant was discarded. The pellets were resuspended in 10 ml 80% EtOH, stirred in a vortex agitator, centrifuged as described above, and the supernatant was discarded. The thermostable α-amylase was added at a dilution of 1:30 with 100 mM sodium acetate buffer, pH 5 (3 ml). Then the centrifuge tube was placed in a boiling water bath for 12 minutes (the tube was vigorously stirred after 4, 8, and 12 minutes). After 0.1 mL Amyloglucosidase was added, it was mixed in a vortex mixer and incubated at 50℃ for 30 min. The contents in the test tube were quantitatively transferred to a 100 ml volumetric flask. The volume was obtained with distilled water and thoroughly mixed. The sample was transferred to a centrifuge tube and centrifuged at 3000 RPM for 10 minutes in a bench centrifuge (ROTINA 380, Hettich LAB TECHNOLOGY, Tuttlingen, Germany). The supernatant (0.1 mL) was transferred to the bottom of a glass tube. To each tube, 3.0 mL GOPOD reagent was added, and the solution was incubated at 50℃ for 20 minutes. D-glucose was used as a control and reagent blank. The absorbance was read in the blank with the reagent at 510 nm.

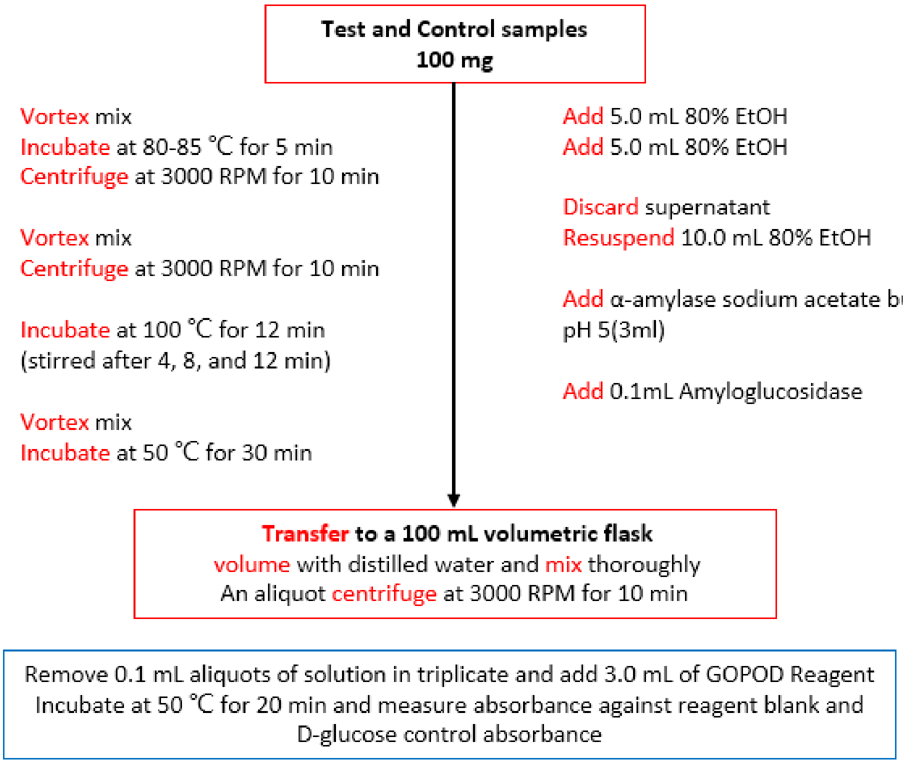


Figure 3.3 Schematic diagram of the determination of total starch.

3.2.8 Determination of the Amylose Content

The amylose content was measured using the Amylose/Amylopectin Assay kit (Megazyme, Ireland, www.megazyme.com), this is a standard method used to measure amylose content (%, w/w).

The sample (20-25 mg, accurate to 0.1 mg) was weighed into a tube. DMSO (1 mL) was added to the test tube and stirred at low speed. The tube was then placed in a boiling water bath and stirred intermittently at high speed on a vortex mixer to ensure the sample was completely dissolved and dispersed. The tube was stored at room temperature for about 5 minutes and add 2 ml 95% (v/v) ethanol, stirring continuously with a vortex mixer. Ethanol, (4 mL) was then added and the tube covered and inverted to facilitate mixing. Starch deposits formed. The tube was left to stand for 15 minutes and then centrifuged at 2,000 g for 5 minutes, discarding the supernatant, and draining for 10 minutes. The pellet was used for the determination of amylose and starch. Added 2 mL DMSO to the tube of starch pellet and place it in a boiling water bath for 15 min and stirred on a vortex mixer at low speed making sure that there were no gelatinous clumps. Added 4 mL of the lectin concanavalin A (Con A) solvent and transferred to a 25 mL volumetric flask. They were diluted with the Con A solvent to the scale (this is solution A). Amylopectin should be precipitated, and amylose was measured in solution A within 2 hours. And transferred 1.0 ml of solution A to 2.0 ml of microcentrifuge tube. Added 0.50 mL of Con A solution. Mixed well and let stand for 1 hour, then centrifuged at 14,000 g for 10 minutes. Transferred 1 mL supernatant to a 15 ml centrifuge tube. Added 3 mL 100 mM sodium acetate buffer, pH 4.5. Mixed well and heated in A boiling water bath for 5 minutes to denature Con A. Placed the tube in a water bath at 40°C for 5 minutes, added 0.1 ml of the starch glucosidase/alpha-amylase mixture, and incubated at 40°C for 30 minutes. Centrifuged the tube at 2,000 g for 5 minutes. 1.0 mL of the supernatant was taken, 4 mL of GOPOD reagent was added, and incubated at 40°C for 20 minutes. Incubated reagent blank and D- glucose control simultaneously. The absorbance of the samples and the D-glucose control was read as blank relative to the reagent at 510 nm. The schematic diagram of the determination of amylose content was shown in the Figure 3.4.

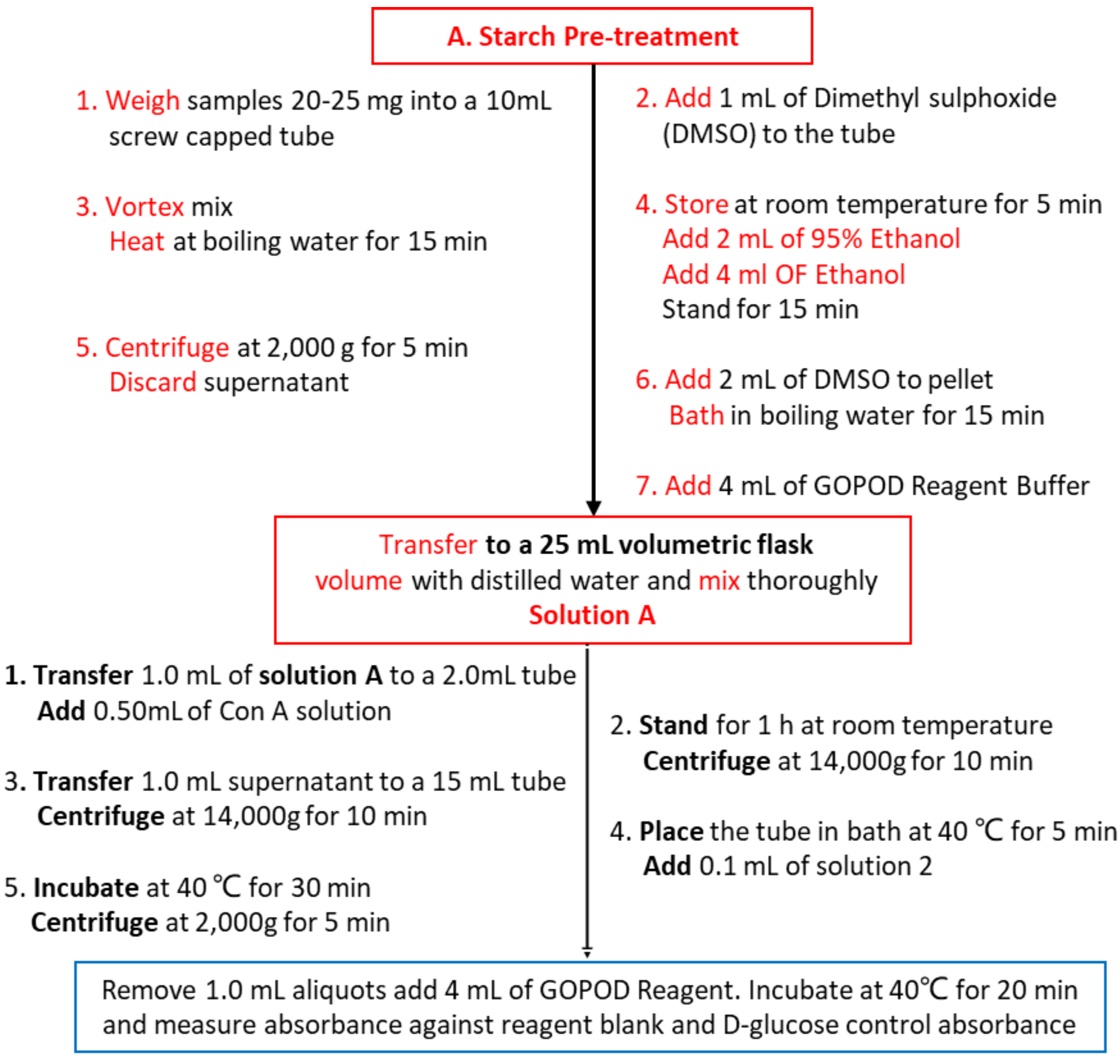


Figure 3.4 Schematic diagram of the determination of amylose content.

Calculation of amylose content (%)

$$Amylose\ content\ (\%) = \frac{Absorbance\ (Con\ A\ Supernatant)}{Absorbance\ (Total\ Starch\ Aliquot)} \times \frac{6.15}{9.2} \times \frac{100}{1}$$

Where 6.15 and 9.2 were dilution factors for the Con A and Total Starch extracts respectively.

3.2.9 Determination of the Resistant Starch Content

Resistant starch (RS) was determined using the Megazyme Resistant Starch Assay (K-RSTAR, Megazyme International Ireland Ltd, Co. Wicklow, Ireland) kit, following the approved AACC method 32–40. (AACC, 2000).

Accurately weighed a 100 ± 5 mg sample directly into each screw cap tube, added 4.0 mL of pancreatic α-amylase (10 mg/mL) containing AMG (3 U/mL) to each tube. Incubated the mixture at 37°C for 16 h in a shaking water. Added 4 mL ethanol (99% v/v) to the mixture to terminate the enzyme reaction, followed by centrifugation for 10 minutes (3000 rpm). The supernatant was separated and used for the determination of non−resistant starch. The RS in the pellet was mixed with 8 mL 50% ethanol, stirred, centrifuged (3000 rpm, 10 min), and the supernatant was poured out. The pellet was then mixed with 2 mL 2 M KOH solution, stirred continuously in ice water for 20 minutes, then sodium acetate buffer (8ml, pH 3.8) and starch glycoside enzyme (3300 U/mL, 0.1 mL) were added. The mixture was incubated in a water bath (50℃ for 30 min). The solution was centrifuged at 3000rpm for 10 minutes. Transfer 0.1 mL aliquots (in duplicate) of either the diluted supernatants into glass test tubes (16 x 100 mm), add 3mL of GOPOD (solution 4), and incubate at 50℃ for 20 min. The absorbance of the mixture was determined at 510 nm, against the reagent blank.

RS was calculated using the following formula, each sample in triplicate.

$$Resistant\ Starch\ (\%) of\ raw\ potatos = \triangle E \times \frac{F}{W} \times 90$$

$$Resistant\ Starch\ (\%) of\ Cooked\ and\ Cooked\ Frozen\ potatos = \triangle E \times \frac{F}{W} \times 9.27$$

△ E: absorbance read against the reagent blank

F: conversion from absorbance to micrograms (the absorbance obtained for 100 µg of D-glucose in the GOPOD reaction is determined and F = 100 (µg of D-glucose) divided by the GOPOD absorbance for this 100 µg of D-glucose.

W: dry weight of sample analysed

3.2.10 Determination Dietary Fibre of Samples.

Total dietary fibre (TDF) content was determined in duplicate using a total dietary fibre assay kit (Megazyme International Ireland Ltd, Wicklow, Ireland) and measurements were recorded for soluble (SDF) and insoluble fibre (IDF) composition, as described by Brennan, Monro, and Brennan (2008).

Weighed 1 g sample into a 400 mL tall-form beaker, added 400 mL MES-TRIS buffer (0.05M, pH 8.2), and dispersed evenly with a magnetic stirrer. Added 50 µL of heat-stable α-amylase and incubated in a shaking water bath at 98-100°C for 30 minutes. Scraped off the deposit on the rim of the beaker with a spatula and rinsed with 10 mL water if necessary. Added 100 µL of protease and incubated in a water bath at 60°C for 30 minutes. Then 5 mL 0.56 HCI and 200 µL amyloglucosidase were added and incubated for 30 minutes in a water bath at 60°C. The final solution was filtered through a sintered glass crucible, ready to be washed twice with 10 ml water at 70°C. The filtrate and water washing were transferred to a 600mL tall-form beaker for SDF determination. The remaining residue was washed twice with 10mL of 95% EtOH and twice with 10mL acetone, and then crucible was sued to determine IDF.

The filtrate and water component of SDF were determined. At 60°C, 95% EtOH of 4 volumes was added to form 1h precipitation. The crucible filtered the precipitate. The precipitation was washed with two parts of 15mL EtOH, 95% EtOH, and acetone, respectively. Both IDF and SDF crucibles were dried overnight in an oven at 103°C and weighed for protein and ash analysis.

Dietary fibre was calculated using the following formula:

$$Dietary\ Fiber\ (\%) = \frac{\frac{R1 +\ R2}{2} - P - A - B}{\frac{m1 + m2}{2}} \times 100$$

Where: R_1= residue weight 1 from m1; R2= residue weight 2 from m2.

m1= sample weight 1; m2= sample weight 2.

A= ash weight from R1;

P=protein weight from R2

B= blank=$\frac{BR1+BR2}{2} - BP - BA$

where, BR= blank residue, BP= blank protein from BR1, BA= blank ash from BR2

3.2.11 The Water Solubility Index (WSI), Water Absorption Index (WAI), and Swelling Capacity (SWC) of Sample

WSI, WAI, and SWC were determined according to the method described by Jozinović, Šubarić, Ačkar, Babić, and Miličević (2016) with slight modifications. The sample (1 g, dry basis) was suspended in 12 mL distilled water, vigorously mixed, and incubated at 85°C for 30 min in a water bath. After incubation, the mixture was cooled and centrifuged at 3000rpm for 15 min. The supernatant was collected in a reweighed aluminium dish (m1), dried by oven at 105°C overnight and weighed (m2). The solid remaining after centrifuging also weighed (m3). WSI, WAI, and SWC were calculated using the following equations:

$$\mathrm{WAI(g/g)} = \frac{m_3}{m_0}$$

$$\mathrm{WSI(g/g)} = \frac{(m_2 - m_1) \times 100}{m_0}$$

$$\mathrm{SWC(g/g)} = \frac{m_3}{\left[m_0 \times \left(1 - \frac{\mathrm{WSI}}{100}\right)\right]}$$

3.2.12 Rapid Visco Analysis (RVA)

The pasting properties of the flour samples were determined using RVA-4 (Newport Scientific Pvt. Ltd., Sydney, Australia) following the method described by Leivas *et al.* (2013). A suspension of 3 g flour was mixed with 25 g distilled water and subjected to a controlled heating and cooling cycle under constant shear where it was held at 50°C for two min, then heated to 95 °C at 6 °C min^{-1}, held at 95 °C for 5 min, cooled to 50°C at 6 °C min^{-1}, and held at 50 °C for 2 min. The total analysis time was 13 min. Peak viscosity (PV), trough, breakdown viscosity (BD), final viscosity (FV), setback viscosity, peak time, and pasting temperature were obtained by the RVA. The date was recorded by a personal computer running Thermocline for windows V3 (TCW3) software.

3.2.13 *In vitro* digestion Predictive Glycaemic Response of the RVA gels.

In vitro digestion of the RVA gels were conducted in triplicate, following the method described by Gao *et al.* (2018). A 3.5 g sample of potato flour from the RVA gels (heated 95°C) was used to determine the predictive glycaemic response. The procedure for measuring the carbohydrate digestibility of the samples were adopted from the method of Foschia *et al*., (2015b), using pancreatin to digest the samples and evaluating sugar release over 120 min. Reducing sugar content was analysed as mg /g sample and plotted against time, and AUC was obtained by dividing the graph into trapezoids as reported previously (Gao, Brennan, Mason, & Brennan, 2016). The procedure is described more fully in section 3.3.6.

3.3 Cooking Properties of Pasta

3.3.1 Cooking Procedure

Fresh pasta (100 g) was cooked in 600 mL boiling tap water for 6 min and strained for 30 s. Cooked pasta was then analysed for CL, SI, WAI and textural properties. After the previous work, the cooking time was normalized to 6 minutes to reduce variability in the potential effects of optimal cooking time on the potential glycaemic impact of the pasta (Lu, Brennan, Serventi, Mason, & Brennan, 2016).

3.3.2 Cooking Loss

The CL equates to the amount of solid substance lost in the cooking water, and was determined according to Lu *et al.* (2016). The cooking water was collected in an aluminium vessel, placed in an air oven at 105 °C and evaporated until constant weight was reached. The residue was weighed and reported as a percentage of starting material.

3.3.3 Swelling Index and Water Absorption Index

The SI of cooked pasta (g water/g dry pasta) was determined according to the procedure described by Cleary and Brennan (2006b). Pasta (100 g) was weighed after cooking and dried at 105 °C until constant weigh reached. The result was expressed as:

$$SI = (Wc - Wd)/Wd$$

Where Wc was the weight of cooked pasta (g) and Wd was the weight of pasta after drying (g).

The WAI of pasta (g/ 100 g) was determined as:

$$WAI = (Wc - Wr)/Wr \times 100$$

Where Wc was the weight of cooked pasta (g) and Wr was the weight of uncooked pasta (g).

3.3.4 Textural Characteristics

Cooked pasta textural properties were determined using a Texture Analyser (TA.XT2, Stable Micro System, UK) equipped with a 50kg load cell. Samples were rested for 10 min after cooking before testing. Firmness and resistance to uniaxial extension of the cooked pasta were determined according to the method described by (Foschia *et al.*, 2015b). Measurements were collected from three different cooking replications. Five strands of cooked strands pasta were placed parallel to each other on a flat metal plate and compressed by the blade.

3.3.5 Colour Measurement

Colour readings of cooked and uncooked pasta were taken using a tristimulus colour analyser (Minolta Chroma meter CR 210m, Minolta Camera Co., Japan). Results were expressed as L* (brightness), a*(redness) and b*(yellowness) (Foschia *et al.*, 2015b). The total colour difference $\triangle E^*$ between the control and potato flour pasta samples were determined by the following formula:

$$\triangle E^* = \sqrt{\triangle L^{*2} + \triangle a^{*2} + \triangle b^{*2}}$$

3.3.6 *In vitro* starch digestibility and glycemic response

The *in vitro* digestion method adopted by Foschia *et al*. (2015a) was used to evaluate carbohydrate digestibility of the pasta (Figure 3.5). This method is relatively quick and less expensive compared to other in vivo and in vitro methods while still having an acceptable level of accuracy (a reported r^2 value of 0.96 between the *in vitro* and human *in vivo* glycemic measurements). This method measured the amount of free reducing sugars released during the enzymatic hydrolysis. Pasta was cooked in boiling tap water (600 mL) according to optimum cooking time, and cut with knife in order to obtain a 2-5 mm size. The samples (2.5 g) were suspended in 30 mL of RO water and placed on a pre-heated 15 place magnetic heated stirring block (IKAAG RT 15, IKA WERKE Gmbit & Co., Staufen, Germany) and held at 37 °C with constant stirring. Stomach digestion was initiated by adding 0.8 mL 1M HCl and 1 mL of 10 % pepsin (Sigma Aldrich, USA) solution in 0.05 M HCl with continued stirring and incubated at 37°C for 30 min. One millilitre of aliquots was taken (time 0) and added to 4 mL ethanol. Amyl glucosidase (0.1 mL) was added to the digestion pot in order to prevent end product inhibition of pancreatic α-amylase. Small intestine digestion was mimicked by the addition of enzyme solution (5 mL of 2.5% Pancreatin (Sigma Aldrich, USA) solution in 0.1 M sodium maleate buffer pH 6) with constant stirring at 37 °C for 120 min and aliquots withdrawn after 20, 60 and 120 min and added to 4 mL ethanol. The samples were stored at 4 °C until analysis of reducing sugar content using the 3.5-dinitrosalicylic acid (DNS). For the measurement of the reducing sugars, all test tubes containing the sample aliquots were centrifuged at 1000 g for 10 min. Clean, dry glass test tubes were placed in a stainless steel test tube stand, then 0.05 mL of a sample aliquot from each replicate was placed in individual glass test tubes. A 0.05 mL reagent blank (RO water), 0.05 mL of 5 mg/mL glucose standard and 0.05 mL 10 mg/mL were placed in separate tubes. Then, 0.25 mL of enzyme solution (1 % Invertase and 1% amyl glucosidase) was added to each glass tube and all the tubes were kept for 20 min at room temperature before 0.75 mL of the DNS (reagent) was added to each tube, the tubes were covered and heated for 10 min in a boiling water bath. The glass tubes were then cooled before adding 4 mL of RO water and the absorbance was read at 530 nm. The spectrophotometer was adjusted to zero using a RO water blank.

Reducing sugar release was calculated as mg /g sample and plotted against time and area under the curve (AUC) was calculated by dividing the graph into trapezoids.

The AUC was calculated by adding the areas under the graph between each pair of consecutive observations. For instance, if we have measurements Y_1 and Y_2 at times T_1 and T_2, then the AUC between those two times is the product of the time difference and the average of the two measurements. This calculation is called the trapezoid rule because of the shape of each region under the curve. There are four points in time for this experiment, and the equation is going to look like this.

$$(T_2 - T_1 \times \frac{(Y_2 + Y_1)}{2}) + (T_3 - T_2 \times \frac{(Y_3 + Y_2)}{2}) + (T_4 - T_3 \times \frac{(Y_4 + Y_3)}{2})$$

The AUC can be calculated between any two time points, but when standardising always divide by 120 min, the whole length of the experiment.

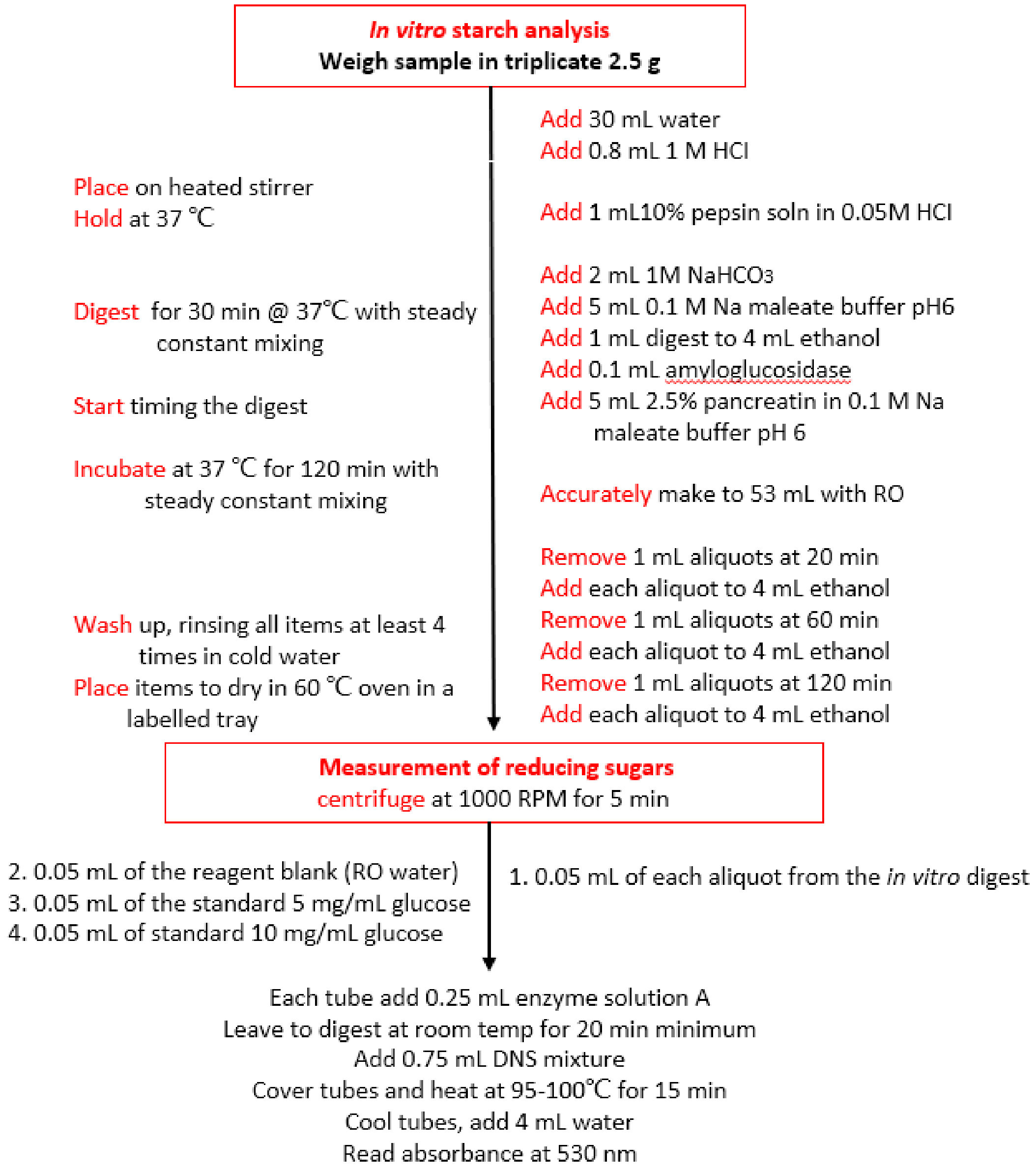


Figure 3.5 Schematic diagram of *in vitro* starch analysis and measurement of reducing sugars

Reducing sugars present per gram of sample was calculated using the following formula:

$$mg\ reducing \frac{sugar}{g} sample = \frac{\big((A - CF) - P\big)}{SA - P} \times D \times G \times E \times \frac{1}{M}$$

Where:

A= sample reading, M= sample weight, B= mean reagent blank, P= mean 0 mg/mL

D= digestion volume, Q= mean 5 mg/mL, E= ethanol dilution factor

R= mean 10 mg/mL, G= Standard glucose concentration

Calculate absorbance value for a standard of 10 mg/mL glucose (SA)

$$\mathrm{SA} = \frac{\left(\left((Q \times 2) - P\right) + R\right)}{2}$$

Calculate correction factor (CF)

$$\mathrm{CF} = \mathrm{B} - \mathrm{P}$$

3.4 Statistical Analysis

The determinations of the total, soluble, and insoluble dietary fibre of the samples were done in duplicate. Other experiments were carried out in triplicate. Statistical software version 17 (Minitab, Sydney, Australia) was used to perform the statistical analysis of the data by one-way analysis of variance (ANOVA), the difference was considered to be significant by Tukey's comparison test ($p < 0.05$).

Chapter 4

Pasting and Starch Digestion of Potato Flour

Abstract

The proximate analysis, pasting, and digestibility properties of raw, cooked, and cooked-frozen potato flour were determined. The cooked, and cooked-frozen, process decreased the content of total starch, amylose content and resistant starch significantly ($P < 0.05$), while influenced water solubility index (WSI), water absorption index (WAI) and swelling capacity (SWC) but increased the dietary fibre markedly ($P < 0.05$). The pasting properties of potato flour were studied by RVA. The viscosity of the cooked potato flour was found to be higher than those of raw and cooked-frozen potato flour but showed the lowest pasting temperature. *In vitro* digestion of the RVA gels was analysed to measure the predictive glycaemic response in potato flour. The cooking process significantly increased the rate of reducing sugar release and the total AUC relating to glucose release of potato flour.

4.2 Introduction

Potato (*Solanum tuberosum L.*) is an essential source of starch that is consumed throughout the world; followed only by rice, wheat, and maize. Potatoes are not only served as vegetables but also used as raw materials for processing into starch derivatives product (Tian *et al.*, 2016). Starch is the primary storage carbohydrate in food crops and is also an essential dietary component in processed food (Sasaki & Kohyama, 2011).

Freshly cooked potato starch has a high GI (Atkinson *et al.*, 2008). Research on the digestibility of the starch of potato can not only reveal the diseases linked to the metabolism of the body but provide dietary guidelines for human nutrition (Blaak *et al.*, 2012; Englyst *et al.*, 1996; Englyst *et al.*, 2003). Therefore, research on starch functionality and digestibility is essential. There are many factors affecting the digestibility of starch, such as the intrinsic properties of starch (including structure (Englyst *et al.*, 1999), and the ratio of amylose to amylopectin (Sasaki *et al.*, 2009)), processing (Simsek *et al.*, 2012), and the presence of other nutrients such as fat, protein, and dietary fibre (Cleary & Brennan, 2006a).

The functional properties of potato starch, such as solubility and swelling power, gelatinisation and retrogradation, are essential to understand the digestibility of potato starch (Wang *et al.*, 2015). The gelatinisation and pasting profiles of flour-water, or starch-water, mixtures are commonly monitored using a RVA, which is a heating and cooling viscometer to measure the resistance of a sample to controlled shear (Gao *et al.*, 2018).

The main ingredient of potato flour is starch, potato flour can be stored safely and used in the homes of consumers as well as in the food industry, in products such as sauces, gravy, bakery, and noodles (Yadav, Guha, Tharanathan, & Ramteke, 2006). Hence the objective of this work was to investigate the pasting and digestion properties of two cultivars of potato (Agria and Nadine) were treated by gelatinisation and further retrogradation to enhance their health value.

4.3 Materials and Methods

4.3.1 Raw Materials

Described in section 3.1

4.3.2 Preparation of Potato Flour

Described in section 3.1.1

4.3.3 Yield (%) and Proximate Analysis of Potato Flour

Described in section 3.2.1 to 3.2.6

4.3.4 Determination of Starch and Dietary Fibre of Potato Flour.

Described in section 3.2.7 to 3.2.10

4.3.5 The Water Solubility Index (WSI), Water Absorption Index (WAI), and Swelling Capacity (SWC) of Sample

Described in section 3.2.11

4.3.6 Rapid Visco Analysis (RVA)

Described in section 3.2.12

4.3.7 *In vitro* digestion Predictive Glycemic Response of the RVA gels.

Described in section 3.2.13

4.3.8 Statistical Analysis

Described in section 3.4

4.4 Results and Discussion

4.4.1 Physical Characteristics of Potato

The main characteristics of the fresh potato are summarised in Table4.1.

Table 4.1 Characteristics of fresh potato, varieties Agria and Nadine

	Fresh Colour	Average weight (g)	Peeling (%)	Dry matter content (%)	Starch content (%)	Moisture (%)
Agria	white	185.02 ± 26.15^{b}	11.92 ± 0.70^{a}	22.43 ± 0.32^{a}	17.33 ± 2.15^{a}	77.57 ± 1.10^{b}
Nadine	white	267.34 ± 30.18^{a}	9.86 ± 0.60^{b}	15.24 ± 0.56^{b}	10.86 ± 1.45^{b}	84.76 ± 0.98^{a}

Mean values ± SD of triplicate determinations.
^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P< 0.05$; according to Tukey's test).

The average weight of the two types of potatoes was quite different, with Agria weighing about 100g less than Nadine. The average weight of a potato can affects the peeling loss during potato flour production, with smaller potatoes having a higher peeling loss than larger potatoes (Kulkarni et al., 1996b). Nadine potatoes had thinner skins, lower starch content (10.86% by wet weight), and higher water content compared to Agria. In contrast, Agria had a thicker skin and contained more starch (17.33% in wet weight) and less water. There was a significant difference in the DM and starch contents of two varieties potato, Agria had higher dry matter and starch contents than Nadine, which was similar to previous reports (Monro, et al., 2009; Singh et al., 2009). DM content and starch content can be affected by many factors. Mohammed (2016) investigated this factor over a 3 year period from 2012 to 2014, using 17 kinds of potatoes from the Himalayas, and found that the DM and starch contents of potato were influenced by variety, property, the location, soil type, and harvesting. It has been reported that the water content of different potato varieties may have a great influence on their blood sugar (Lynch et al., 2007).

4.4.2 Yield and Proximate Analysis of Potato Flour.

The yield, moisture, fat, ash, protein, and phosphorus content of potato flour samples of the different cultivars used in the different processing conditions are shown in Table 4.2.

Table 4.2 Yield (%) and proximate analysis of potato flour of the different potato cultivars.

Sample	Yield %	Moisture %	Fat %	Ash %	Protein %
RAF	18.88 ± 0.25^{a}	9.69 ± 0.07^{a}	0.71 ± 0.07^{a}	4.05 ± 0.07^{a}	8.68 ± 0.04^{a}
CAF	18.37 ± 0.31^{ab}	9.27 ± 0.06^{b}	0.50 ± 0.08^{bc}	3.59 ± 0.05^{b}	7.49 ± 0.04^{c}
CFAF	17.13 ± 0.29^{d}	8.66 ± 0.09^{cd}	0.48 ± 0.05^{bcd}	3.45 ± 0.05^{c}	7.45 ± 0.03^{c}
RNF	18.24 ± 0.24^{ab}	8.84 ± 0.11^{c}	0.57 ± 0.02^{ab}	3.21 ± 0.03^{d}	7.96 ± 0.04^{b}
CNF	17.94 ± 0.22^{bc}	8.57 ± 0.09^{cd}	0.36 ± 0.05^{cd}	2.93 ± 0.05^{e}	6.95 ± 0.04^{d}
CFNF	17.45 ± 0.19^{cd}	8.49 ± 0.11^{d}	0.34 ± 0.03^{d}	2.91 ± 0.02^{e}	6.91 ± 0.03^{d}

Mean values ± SD of triplicate determinations.
^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different (P< 0.05; according to Tukey's test).

The yield of raw Agria potato flour and raw Nadine potato flour was 18.88% and 18.24% respectively, which was higher than that of cooked-frozen flours, combined with the dry matter content of two cultivars potato, the Agria tubers gave a higher flour production yield than Nadine potatoes. Naumann, Koch, Thiel, Gransee, and Pawelzik (2020) reported that the DM content was proportional to the starch content of potato and that high DM content of potato varieties was more conducive to further processing and improved texture and shape of processed products.

The moisture content is the main component of fresh potato tubers, and an important index of potato flour as the amount of the moisture can directly affect the shelf life of potato flour. It can be seen from Table 4.2 that there were significant differences in the moisture contents of the different potato flour. By comparison, the moisture of wheat flour was about 13%, so the moisture of all 6-potato flour was lower than that of wheat flour. There was a significant difference in the chemical composition among the potato flour samples. For instance, the fat, ash and protein contents of potato flour ranged from 0.34%-0.71%, 2.91%-4.05% and 6.91%-8.68% respectively, which were close to the values reported by other researchers (Misra & Kulshrestha, 2003a; Pinhero *et al.*, 2016; Yadav *et al.*, 2006). The levels of fat, ash, and protein decreased as the potato were processed, differences between varieties could be attributed to genetic variation and plant origin (Lynch *et al.*, 2007).

4.4.3 The Influence of Processing Conditions of Starch Characteristics, Dietary Fibre and Phosphorus contents of Potato Flour

The influence of processing on starch, dietary fibre and phosphorus of potato flour are given in Table 4.3. The total starch, amylose content, and RS have been shown to be important nutritionally and implied to human health. Therefore, it is important to understand this property of potato starch, which plays a vital role in the digestibility of potato products and the blood glucose response of human subjects (Lynch *et al.*, 2007).

The different treatments affected the quantity of the total starch of potato flour ($P<0.05$). The starch content of Agria potato varieties was higher than that of Nadine, which can be attributed to the great difference of potato varieties in cultivation (Singh, Kaur, McCarthy, Moughan, & Singh, 2008). The total starch content of uncooked potatoes varied significantly, between 77.45% and 70.18%, respectively (Table 4.3). The total starch content of Agria was significantly higher than that of Nadine. The freezing process reduced the total starch content. The reason for this may be that freezing limits the availability of water (Table 4.2), thus frozen potato flour exhibited less quantity of total starch compared to the raw and cooked potato flour. However, this was different to the findings of Zhao, Andersson, and Andersson (2018) who reported that the total starch content of raw potato and cooked potato were similar, indicating that the total starch content did not change with cooking and storage. The total starch content of potato flour during selected processing conditions depend on the availability of water (Nayak, Berrios, & Tang, 2014).

The amylose content of Agria and Nadine flour in raw, cooked, and cooked and frozen samples was 24.15% and 20.13%, 18.13% and 14.18%, 19.23% to 15.55%, respectively (Table4.3). It was observed that there were significant differences in amylose content between raw, cooked, and retrograded potato varieties. The amylose content of potato flour decreased in cooked, which is similar to the values reported in rice (Jain *et al.*, 2012). It is also possible that potato cooked in water lose some amylose and reduced the linear chains of amylose for binding (Pinhero *et al.*, 2016). During gelatinisation, starch granules expand and undergo irreversible ordered, and disordered, phase transition to form a gel. Typically, the swelling granules are abundant in amylopectin, the amylose diffuses from the swelling gel granules, and is dissolved preferentially. The crystallinity of the gelatinised starch gel is attributed to the gelation and crystallization of amylose after the gelatinised starch gel is cooled and stored during retrogradation (Pinhero *et al.*, 2016).

After the gelatinised starch gel was cooled and stored, the amylose in the retrograded potato flour increased due to the gelation and crystallization of amylopectin. Starch which is abundant in amylose has more extensive hydrogen bond binding, so their structure has more crystallinity than other starch, making them more difficult to swell or gelatinise during cooking but tend to enhance starch retrogradation (Thorne, Thompson, & Jenkins, 1983). As a consequence, Agria varieties, with high amylose levels, may help slow digestion and prevent a rapid rise in blood sugar levels after meals.

The RS was highest in raw potato flour (RAF and RNF), and lowest in cooked potato flour (CAF and CNF). The main reason for this phenomenon may be that starch molecules are granular and undigestible. After cooking, starch gelatinises and become easily digestible. However, in the process of retrogradation, part of starch becomes indigestible as RS (Monro & Mishra, 2009; Monro, Mishra, Blandford, Anderson, & Genet, 2009). Comparing the different potato varieties, Agria had a higher RS than Nadine, which might be due to the higher phosphorus content in Nadine (Table 4.3). Some researchers have reported that phosphorus in potato starch granules was negatively correlated with the degree of retrogradation (Hopkins & Gormley, 2000; Muhrbeck & Eliasson, 1991). However, the relationship between phosphorus and potato starch retrogradation remains controversial. Jane, Kasemsuwan, Chen, and Juliano (1996) reported that abundant phosphate in starch inhibited coagulation and retrogradation. Potato starch with amylose content had a high phosphate content, but the rate of starch retrogradation was faster than expected. As mentioned previously, it is believed that amylose is digested slowly, while amylopectin is digested quickly. The high amylose content in starch is essential for the establishment of a continuous amylose matrix that is needed to maintain the integrity of the embedded swollen starch granules. These embedded swelling particles are the major determinants of the rheological properties of starch pasting or gelation (Tsai, Li, & Li, 1997). Therefore, in general, RS content of potato flour depends on a delicate balance between amylose and phosphorus. In a recent study, Raatz, Idso, Johnson, Jackson, and Combs (2016) found that boiled and refrigerated potatoes contained more RS than heated or reheated potato. It is generally believed that the RS in raw potato (RAF and RNF) are mainly RS2, in which the starch granules are resistant to enzyme digestion, and the RS produced by boiled and refrigerated potato belonged to RS3 (Brown, McNaught, & Moloney, 1995). Freezing after cooking reduced the blood sugar effect of potatoes and increased the amount of dietary fibre produced by the production of RS. After retrogradation, the RS doubled to 9.24% in Agria. According to food regulations regarding health claims associated with DF, potato flour can be classified as high in DF (> 6%). It may have a health advantage in the potato diet due to RS as the prebiotic activity, a benefit that has been demonstrated in cereal (Bird & Topping, 2001).

The content of TDF in Agria (9.40-12.71%) was significantly higher ($p < 0.05$) than that of Nadine (6.59-11.48%), whether they were cooked, or cooked-frozen. Compared with the uncooked potato samples, the content of TDF in Agria and Nadine increased after cooking, mainly due to the effect of heating and refrigeration in forming retrograded starch and RS3 (Varo, Veijalainen, & Koivistoinen, 1984). Some previous studies have also reported that cooking increased the DF content of potatoes (Dhingra, Michael, Rajput, & Patil, 2012). The SDF of Agria and Nadine were unchanged during different process, these results were similar to previous researcher (Thed & Phillips, 1995; Varo, Laine, & Koivistoinen, 1983), possibly because the major SDF components of potato flour have been found to be pectin and hemicellulose (Ross, English, & Perlmutter, 1985). Cooked, and cooked-frozen flours appeared to increase the IDF of the potato flour. It has been suggested that this may be due to the formation of compounds between polysaccharides in foods and other compounds, such as lipids and proteins (Yadav, 2011). Although the content of non-starch polysaccharide is low, potatoes flour can still be regarded under health claims as "high dietary fibre content" due to the formation of RS (Monro & Mishra, 2009). Dietary fibre affects food by reducing the rate at which glucose is broken down and absorbed, thereby reducing the build-up of glucose and the metabolism of carbohydrates (Brennan, 2005b). Therefore Agria, with high TDF, may slow carbohydrate metabolism and reduce blood sugar effects.

Table 4.3 The content of Starch and Dietary Fibre of potato flour

Sample	Total starch (%, g/100g)	Amylose content (%, g/100g)	Resistant starch (%, g/100g)	SDF (%, g/100g)	IDF (%, g/100g)	TDF (%, g/100g)	Phosphorus (%, g/100g)
RAF	77.45 ± 0.25^{a}	24.15 ± 0.14^{a}	45.25 ± 0.28^{a}	3.87 ± 0.08^{a}	5.53 ± 0.13^{c}	9.40 ± 0.05^{c}	0.0485 ± 0.0019^{d}
CAF	77.89 ± 0.18^{a}	18.13 ± 0.12^{d}	4.40 ± 0.14^{d}	3.73 ± 0.08^{a}	5.59 ± 0.09^{c}	9.32 ± 0.08^{c}	0.0734 ± 0.0026^{b}
CFAF	73.23 ± 0.24^{b}	19.23 ± 0.11^{c}	9.24 ± 0.11^{c}	3.77 ± 0.08^{a}	8.94 ± 0.11^{a}	12.71 ± 0.10^{a}	0.0392 ± 0.0016^{e}
RNF	70.18 ± 0.17^{c}	20.23 ± 0.15^{b}	42.05 ± 0.18^{b}	3.04 ± 0.15^{b}	3.55 ± 0.11^{d}	6.59 ± 0.12^{d}	0.0565 ± 0.0023^{c}
CNF	70.34 ± 0.14^{c}	14.18 ± 0.12^{f}	2.32 ± 0.11^{e}	3.09 ± 0.14^{b}	3.45 ± 0.13^{d}	6.54 ± 0.14^{d}	0.0913 ± 0.0024^{a}
CFNF	64.25 ± 0.15^{d}	15.55 ± 0.12^{e}	4.51 ± 0.18^{d}	3.12 ± 0.12^{b}	8.36 ± 0.08^{b}	11.48 ± 0.11^{b}	0.0471 ± 0.0015^{d}

Mean values ± SD of triplicate determinations.

^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different (P< 0.05; according to Tukey's test).

From Table 4.3, the phosphorus content ranged from 0.0392% to 0.0913%, this is similar to data reported by other researchers on phosphorus levels in other potato varieties, 0.0596% to 0.1022% (Kim, Wiesenborn, Orr, & Grant, 1995), 0.049% to 0.122% (Morrison *et al.*, 2001). Nadine was significantly higher phosphorus content than Agria ($P<0.05$). Comparing different varieties of potato, amylose and phosphorus levels were negatively associated, a finding similar to that of Singh, McCarthy, and Singh (2006), the content and form of phosphorus in potato starch has been reported to be influenced by growth conditions, storage conditions and processing methods (Cottrell, Duffus, Paterson, & Mackay, 1995).

The process of cooked changed the phosphorus content of potato flour. This may be due to an increase in phosphorus content associated with an increase in the proportion of amylopectin in starches. It is speculated that amylose and phosphorus will have opposite effects on the functional properties of potato starch. Phosphorylated starches from different sources, including potatoes, have been reported to have higher digestibility than non-phosphorylated starches because the phosphorous group reduces the sensitivity to enzymatic hydrolysis in vitro (Sitohy & Ramadan, 2001). Most of the phosphorus in potato starch is located in the B chain of amylopectin, and there is no phosphate group in the unit chain with less than 20 residues. Therefore, high phosphorus content is usually related to the high amylopectin content of starch (Karim *et al.*, 2007). However, the mobility of starch molecules decreased during freezing, which reduced the number of phosphate groups in amylopectin molecules (Pinhero *et al.,* 2016). As a result, the higher the content of phosphorus in Nadine, may be associated with amylopectin contents, and this in turn may lead to faster starch digestion, starch hydrolysis.

4.4.4 WSI, WAI, and SWC of Potato Flour

Table 4.4 summarises the Water Solubility Index (WSI), Water Absorption Index (WAI), and Swelling Capacity (SWC) of potato flour from different varieties and treatments. The CAF and CNF showed the lowest WSI (7.43 and 7.01 g/100 g dry solids). The solubility of potato tubers has been reported to be mainly due to the solubility of the starch granules, which in turn depends on the amylose content (Singh, Singh, Sharma, & Saxena, 2003). Starch with lower amylose content has been shown to have a higher swelling force during heating. The hydration and swelling of starch during cooking reflects the degree of the interaction between the amorphous domain and the crystalline domain of starch. The ratio of amylose to amylopectin, and the distribution of amylose and amylopectin, may affect the degree of this interaction, resulting in changes in the swelling and solubility of the starch (Li, Shao, & Tseng, 1995). In this study, the WSI and WAI of Agria was significantly higher than that of Nadine after the same treatment, which might be due to the fact that the amylose content of Nadine potato flour was lower than Agria. Additionally, the significantly higher phosphorus content in Nadine flour may lead to relatively high solubility and water absorption. The solubility and water absorption of potato flour decreased with the gelatinisation of starch during cooking and decreased during starch retrogradation. WSI reflects the degree of starch degradation (Que, Mao, Fang, & Wu, 2008). The lower solubility of cooked potato flour was due to the more durable hydrophilicity of starch in the process of processing. It has been observed that the solubility of retrograded starch was lower than that of raw starch (Haralampu, 2000). The main reason for this observation appears to be that the retrogradation of starch causes the gelatinised starch to recrystallize to form a denser structure. Similarly, it can be speculated that the starch in the sample may form amyloid-lipid complexes and bind with other macromolecules to limit the absorption of starch particles (Liu, Arntfield, Holley, & Aime, 1997).

The SWC of potato flour increased with cooking, and reduced with retrogradation (Table 4.4). Swelling power represents the hydration of starch under certain cooking conditions. The SWC of Agria and Nadine increased from 5.37 to 6.96 and 6.41 to 7.66, and then decreased to 4.92 and 5.25 respectively. Phosphorus content was highly positively associated with swelling, potato starch with higher phosphorus content has higher swelling power (Singh, McCarthy, Singh, & Moughan, 2008). It has been reported that a weak internal structure can be caused by negatively charged phosphate ester groups in potato starch granules, and this may be the reason for the observations or our results, and the starch phosphorus content may have a more significant impact on the swelling force and solubility of potato starch (Jane *et al.*, 1999). The differences in the morphology of the starch granules may also be responsible for the differences in the swelling and solubility of all starches. It has been reported that the swelling of starch depends on the water-holding capacity of starch molecules by hydrogen bonding. The hydrogen bond of the double helix structure in the stable microcrystalline is destroyed during gelatinisation and replaced by the hydrogen bond of water. The swelling is regulated by the crystallinity of starch (Karim *et al.*, 2007). In this study, phosphorus content was associated with swelling, and significantly negatively related with solubility.

Table 4.4 Illustrating the Water Solubility Index (WSI), Water Absorption Index (WAI), and Swelling Capacity (SWC) of potato flour

Sample	WSI (g/100g)	WAI (g/g dry solids)	SWC (g/g dry solids)
RAF	10.03 ± 0.05^{a}	6.88 ± 0.04^{c}	5.37 ± 0.06^{d}
CAF	7.43 ± 0.09^{d}	9.64 ± 0.09^{a}	6.96 ± 0.08^{b}
CFAF	8.06 ± 0.08^{c}	5.88 ± 0.07^{e}	4.92 ± 0.07^{f}
RNF	8.99 ± 0.06^{b}	6.62 ± 0.12^{d}	6.41 ± 0.09^{c}
CNF	7.01 ± 0.03^{e}	8.53 ± 0.09^{b}	7.66 ± 0.05^{a}
CFNF	7.48 ± 0.02^{d}	5.58 ± 0.05^{f}	5.25 ± 0.09^{e}

All measurements are mean values ± SD of triplicate determinations.
[a,b,c,d] Mean values within a column with unlike superscript letters are significantly different (P< 0.05; according to Tukey's test).

4.4.5 Pasting Properties of Potato Flour Samples

The gelatinisation characteristics of potato flour is an indication of its molecular degradation and gelatinisation degree and stability. The pasting properties of the potato flour were obtained using the RVA (Table 4.5). The physicochemical properties, such as amylose content, phosphorus content, and particle size distribution, have been shown to be the main factors that determine the gelatinisation and rheological properties of potato starch (Singh, Kaur, & McCarthy, 2007).

Table 4.5 The Pasting Properties of Potato Flour Samples

Sample	Peak Viscosity (mPa · s)	Trough Viscosity (mPa · s)	Breakdown Viscosity (mPa · s)	Final Viscosity (mPa · s)	Setback (mPa · s)	Pasting Temp (℃)
RAF	3361 ± 31^{e}	1605 ± 18^{e}	1756 ± 13^{e}	2381 ± 24^{a}	776 ± 8^{a}	59 ± 0.93^{c}
CAF	3677 ± 23^{c}	1795 ± 24^{c}	1882 ± 17^{c}	2153 ± 23^{d}	358 ± 11^{e}	68 ± 0.65^{a}
CFAF	3155 ± 25^{f}	1483 ± 19^{c}	1672 ± 19^{f}	2217 ± 19^{c}	734 ± 9^{ab}	63 ± 0.70^{b}
RNF	3775 ± 28^{b}	1801 ± 21^{b}	1974 ± 18^{b}	2263 ± 15^{b}	462 ± 9^{c}	54 ± 0.65^{d}
CNF	4123 ± 26^{a}	1911 ± 19^{a}	2212 ± 16^{a}	2044 ± 11^{f}	133 ± 11^{f}	64 ± 1.05^{b}
CFNF	3498 ± 29^{d}	1666 ± 17^{d}	1832 ± 14^{d}	2083 ± 16^{e}	417 ± 12^{cd}	60 ± 0.55^{c}

Mean values ± SD of triplicate determinations.
^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P< 0.05$; according to Tukey's test).

In the entire testing process, the cooked potato flour (CAF and CNF) always showed the highest viscosity, and the cooked-frozen potato flour (CFAF and CFNF) showed the lowest viscosity among the flour samples. This indicates that gelatinisation can significantly increase the viscosity of potato flour, and that retrogradation can decrease the viscosity. Such observations are similar to those previous reported (Colussi *et al.*, 2014; Saartrat, Puttanlek, Rungsardthong, & Uttapap, 2005). Potato flour showed a high peak viscosity due to its large size and high phosphorus content (Singh, McCarthy, *et al.*, 2008). Comparing the different potato flours, Nadine potato flour exhibited the highest peak viscosity, which might be attributed to its lower amylose content than Agria (Table 4.2), and this is in agreement with Singh, Singh, Sharma, and Saxena (2003). A negative correlation was found between peak viscosity and flour from different varieties starch content ($r = 0.918$, $p < 0.05$) (Singh *et al.*, 2009).

The viscosity of starch has been shown to be affected by the leaching of amylose, the friction between the swelling particles, the swelling of the granules, and the free water competition between the leached amylose and the remaining ungelatinized particles (Liu, Ramsden, & Corke, 1999).

A reduced viscosity of potato flour was observed after cooking and refrigeration process. It may be that the leaching of amylose, the formation of the amylose-lipid complex, the friction between the particles, the swelling of the particles, and the free water competition between the leached amylose and the remaining ungelatinized particles affect the viscosity (Singh, McCarthy, *et al.*, 2008). In other words, the low viscosity of CFAF and CFNF can be attributed to the significant loss of particle rigidity during treatment (Yadav, Guha, Tharanathan, & Ramteke, 2006). Compared with the raw potato flour and cook potato flour, the viscosity parameter of the starch of the cooked-frozen potato flour was lower. This property might be caused by the destruction of particles subjected to hydrolysis during heating, which has been argued to improve the content of short linear molecules (Yu *et al.*, 2015).

In the pasting characteristic parameters, the peak viscosity represents the swelling capacity of the sample, the values for trough and breakdown represent the stability and shear resistance of the gelatinised sample, setback and final viscosity represent the retrogradation characteristics of the sample (Deng, Mu, Zhang, & Abegunde, 2013). Agria flour showed higher setback, while Nadine showed lower setback, reduced recombination during cooling in low amylose, and high amylose showed higher setback. Breakdown and setback have been reported to be closely related to amylose content. Amylose content was positively correlated with setback ($R = 0.784$) and negatively correlated with breakdown ($R = -0.769$) (Singh, Kaur, Ezekiel, & Singh Guraya, 2005).

From Table 4.5, Agria and Nadine showed the highest pasting temperature (68°C) and the lowest (54°C), respectively. Singh *et al.* (2005) studying pasting properties of flour from six different potato cultivars found that pasting temperature ranged from 66.5 °C to 68.1 °C, similar values to those found for Agria and Nadine potato flour.

4.4.6 *In vitro* Predictive Glycemic Response for potato flour gel.

An *in vitro* enzymatic digestion was performed to evaluate the predictive potential glycemic response of the potato flour from the RVA gels. The values for the samples are shown in Fig 4.1 and Fig 4.2, and these illustrate a significant difference between the three different treatments of potato flour. The values of reducing sugar of the cooked potato flour (CAF and CNF) increased dramatically in the first 20 min, and the raw potato flour (RAF and RNF) showed the lowest values of reducing sugar. Raw potato starch had a high resistance to enzymatic hydrolysis, but conventional cooking methods makes it more easily to digest. The RS content of raw potato powder changed from about 42% to only 3% when cooked (Table 4.3). Previous reports have stated that the RS content increased after cooling or freezing, but the potato became digestible again after reheating (Kingman & Englyst, 1994). The amount of RS had been shown to reduce the digestibility of starch products (Tudorica, Kuri, & Brennan, 2002). Nadine showed a higher reducing sugar response to Agria, and can be considered easier to digest than Agria potatoes, possibly because of the dietary fibre and RS content in Agria. Many studies have shown that there may be considerable statistical differences in digestibility between potato varieties (Henry, Lightowler, Strik, & Storey, 2005; Mishra, Monro, & Hedderley, 2008). Little research had been done on the effect of different potato varieties on the rate of reducing sugar release during digestion in potato pastes.

Generally, potato starch has very low digestibility levels in its raw state, where the starch molecules are tightly organized into starch granules (Mishra *et al.*, 2008). When potato is cooked, and the starch chains are hydrated during gelatinisation, the starch is fully digested by amylase (fast-digesting starch, RDS) in almost 20 minutes. However, cooling of potato led to a portion of the starch becoming indigestible (RS), and a larger proportion of the starch being slowly digested (SDS), between 20 and 120 minutes. When cooked potato was cooled or frozen for a period after cooking, the in vitro digestibility of starch decreases (CFAF and CFNF). The reduction in the digestibility of potato after cooking and refrigeration could be attributed to partial starch retrogradation, which increased RS content (Table 4.3). The increase in RS could be attributed to the reduction of amylose (Monro, Mishra, *et al.*, 2009).

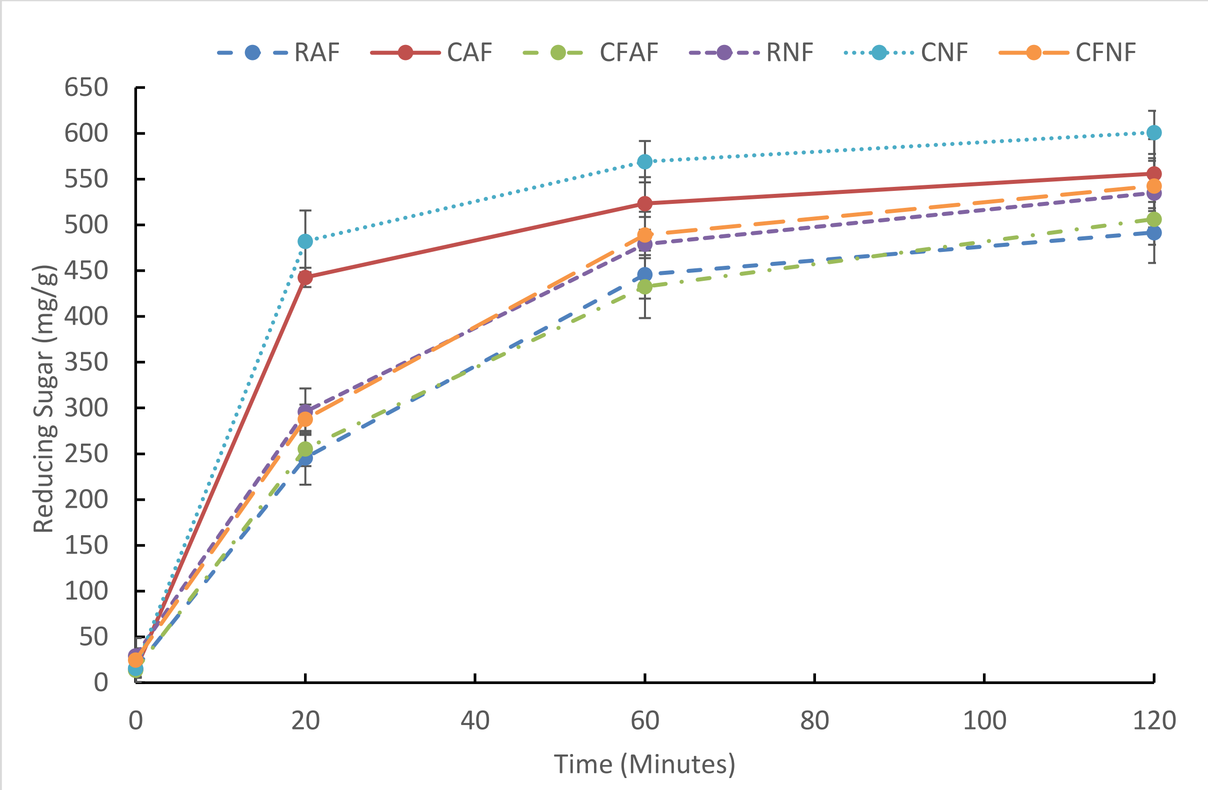


Figure 4.1 Amount of reducing sugar released during *in vitro* digestion for potato flour

A comprehensive parameter for the digestibility is the AUC of a digestion process (Goñi, García-Alonso, & Saura-Calixto, 1997)). Fig. 4.2 shows the standardised AUC values of the potato flour from the RVA gels. Processing methods of potato seemed to have a significant effect on the AUC reducing sugars levels ($p < 0.05$). For instance, the AUC values of cooked potato flour (CAF and CNF) were higher than raw potato flour gel (RAF and RNF) and resistant potato flour gel (CFAF and CFNF), by approximately 25%. Cooked potato flour contained the most amount of digestible starch. Processing has been shown to change the glycemic response of postprandial starch by destroying cell wall and granule structure, and gelatinisation increased the GI (Fernandes *et al.*, 2005). During cooling and frozen, the retrogradation of starch formed a more resistant potato flour (CFAF and CFNF), which delays digestion and absorption, and reduced the glycemic response. Therefore, the GI of potato processed products can be reduced by optimizing food processing technology to control gelatinisation and retrogradation.

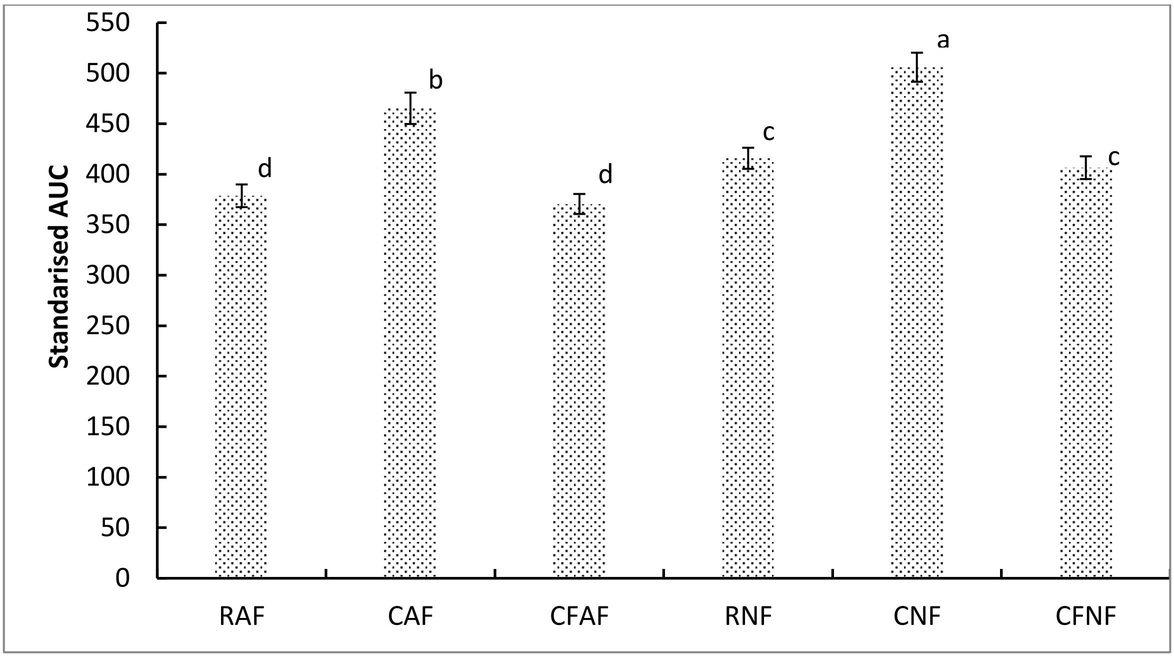


Figure 4.2 Values of area under the curve (AUC) for potato flour.

4.5 Conclusion

The benefits of low GI foods in reducing insulin demand, improving satiety, improving glycemic control in people with diabetes, lowering blood lipid levels, and increasing colonic fermentation have been well documented. Potato is a staple food in developed countries and producing low GI potato foods would help reduce the overall GI of the diet in those countries.

In this chapter, potatoes (Agria and Nadine) were treated by gelatinisation and further retrogradation. The nutritional composition, viscosity characteristics, and digestive properties of potato flour obtained by different treatment methods were evaluated, and it was shown that the total starch content of the two varieties of potato flour did not changed with the processing method and storage. Cooking significantly reduced amylose and RS content, but these were significantly increased in cooked-frozen. Gelatinisation decreased the solubility but increased the swelling the viscosity. The gelatinisation process changed the physicochemical properties of potato flour, which resulted in the rapid digestion and the hyperglycemic response. However, the process of retrogradation changed the content of amylose and RS, which reduced the glycemic response of potato flour.

Comparing two different kinds of potato flour, the difference of chemical composition led to the various physical and chemical characteristics of potato flour samples. The delicate balance between amylose and phosphorus directly determined the RS content and ultimately affected potato GI. Therefore, potato and their products produced a different glycemic response, which depended on the variety of potato, starch structure, and processing method.

It is a condition that reduced the digestibility of potato flour, and subsequent gastrointestinal reactions were those that reduced the destruction and gelatinisation of starch granules, increased the formation of amylose, and increased the retrogradation of starch during cooling and storage.

Therefore, this study provides a theoretical foundation for the application of potato flour on food, the importance and popularity of potato as a food crop will be widely used in the food industry.

Chapter 5

Study on Functional and Pasting Characteristics of Potato and Wheat Flour Blends

Abstract

The functional and pasting characteristics of wheat flour, and their blends with three different treatments of potato flour at 10 to 50% were investigated. The effect of the characteristics of the mixtures on the protein, total starch, amylose, dietary fibre, resistant starch, solubility, swelling capacity, water absorption, and pasting properties were studied. The results showed that the moisture, protein and amylose content decreased with the increasing levels of potato flour in the blend, but the total starch, dietary fibre and resistant starch increased with potato flour addition. Compared with wheat flour, potato flour had higher pasting characteristics and lower solubility. The addition of potato flour increased the water solubility index (WSI), water absorption index (WAI), and swelling capacity (SWC) of the blends, the peak viscosity, final viscosity and setback increased with an increase in the potato flour from 10%-50%.

5.2 Introduction

Flour is usually a fine powder made from grains or other starch products, such as corn, wheat, and rice, and from tubers and roots of potato, sweet potato, and cassava, and is part of a staple diet for many countries (Adeleke & Odedeji, 2010). Flour blends are mixtures of wheat and non-wheat flours used for bread, baked products, noodles, pasta, and snacks, to be used for traditional or new functional products (Menon, Majumdar, & Ravi, 2015). Potato (*Solanum tuberosum*) is one of the four major food crops in the world, and is utilized by manufacturers because of its nutritional properties and storage stability (Li *et al.*, 2018). In addition, potato flour is rich in large amounts of carbohydrates, protein, dietary fibre, minerals, and vitamins, compared with wheat flour, potato flour shows different phytochemicals and protein, which can provide different nutrients (Zhou, Mu, Ma, & Sun, 2019). Potato flour is cheap, nutritious, and an excellent source of carbohydrates. Replacing wheat flour with potato flour may enhance the nutritional properties of a product and improve its sensory properties. However, with the addition of potato flour, the processing quality of composite flour changes, so it is very important to explore the characteristics of flour blends.

There are few studies on the potato and wheat flour blends, many researchers have focused on the application of composite flour to products, such as bread (Liu, Mu, Sun, Zhang, & Chen, 2016; Liu *et al.*, 2017), noodles (Kang *et al.*, 2017) and bakery (Misra & Kulshrestha, 2003b; Vasantharuba Seevaratnam, Premalatha, Sundaram, & Arumugam, 2012) products. However, in the development of any food products from starchy crops, the knowledge of their physicochemical properties, in particular, those of the starch, which is the major component, is needed to predict behaviour under given processing conditions. The pasting characteristics of starch can be related to the swelling and solubility properties of a particular starch (Katayama, Tamiya, & Ishiguro, 2004). Zaidul, Yamauchi, Kim, Hashimoto, and Noda (2007) incorporated potato starch into wheat flour, the pasting characteristics of the mixture were studied by RVA, and the results showed that the peak viscosity, peak time and final viscosity of the mixture were higher than that of wheat flour. Adeleke and Odedeji (2010) investigated the functional properties of wheat and sweet potato tuber flour which were blended using different ratios, the results revealed that the addition of the sweet potato flour significantly affected the functional properties of products.

Thus, understanding the functional characteristics and pasting behaviour of starch and flour are significant in the development of starchy products. In this study, the effect of the characteristics of the five different potato and wheat flour blends fractions (10%, 20%, 30%, 40%, 50%) were studied in terms of the change of protein, total starch, amylose, dietary fibre, RS, solubility, swelling capacity and water absorption. The pasting behaviour is essential for the potato and wheat flour blends characteristics and functionalities, useful information such as pasting temperature, peak viscosity, and the breakdown and setback value can be obtained from the RVA.

5.3 Materials and Methods

5.3.1 Raw Materials

Described in section 3.1

5.3.2 Preparation of Potato Flour

Described in section 3.1.1

5.3.3 Preparation of Blended Samples

Described in section 3.1.3

5.3.4 Proximate Analysis of Blended Samples

Described in section 3.2.3 to 3.2.6

5.3.5 Determination of Starch and Dietary Fibre of Blended Samples.

Described in section 3.2.7 to 3.2.10

5.3.6 The Water Solubility Index (WSI), Water Absorption Index (WAI), and Swelling Capacity (SWC) of Sample

Described in section 3.2.11

5.3.7 Rapid Visco Analysis (RVA)

Described in section 3.2.12

5.3.8 Statistical Analysis

Described in section 3.4

5.4 Results and Discussion

5.4.1 Functional Characteristics of Wheat and Potato Flour Blends

The functional characteristics of raw ingredients are very important as these determine the application and use of food material in various food products (Horstmann, Lynch, & Arendt, 2017). However, potato and wheat flour blends have not been studied extensively. In order to better design product formulations with potato and wheat flour this study focused on the effects that potato and wheat flour blends exerted on the functional characteristics and the influence of the gelatinisation properties of the sample.

5.4.1.1 Nutritional analysis of wheat and potato flour blends.

The basic nutritional analysis of the wheat and potato flour blends with different proportions are shown in Tables 5.1-5.3. The main component of wheat flour and potato flour was starch. Compared with wheat flour, the content of RS in raw potato flour was relatively high, but the opposite was true for cooked and cooked- frozen potato flour. The content of amylose, protein, and moisture of potato flour was slightly lower than that of wheat flour, which was related to the nutrient composition of raw materials and flour making process (Ihekoronye & Ngoddy, 1985). However, potato flour always exhibited higher dietary fibre values than wheat flour.

The moisture and protein contents of the blends decreased as more potato flour was added to wheat flour. The moisture content of a product is an important indicator of food quality and predicting its shelf stability. All the values of the blended samples were within the acceptable limit of dry matter (Adeleke & Odedeji, 2010). The protein content of potato flour in the tables is lower than that of wheat flour. However, research has shown that potato protein contained eight essential amino acids, while wheat flour protein lacked lysine (Ijah *et al.*, 2014), so the nutrition of wheat and potato flour blends could be regarded as more balanced. Samaan, El‐Khayat, Manthey, Fuller, and Brennan (2006) illustrated that the cooking loss and firmness of pasta was related to the protein content, and gluten strength, of the flour used. The relationship between protein (gluten) content and pasta texture and cooking properties are linked to the ability of the proteins in pasta to form a tenacious dough structure during mixing and a firm viscoelastic matrix during cooking. Therefore, a decrease of protein content in semolina is generally linked to a reduction of pasta hardness and an increase of cooking loss.

In terms of total starch content, when the potato flour increased, the total starch of potato flour and wheat flour blends also increased, which appeared to be affected by the total starch content of the potato flour. The starch content of potatoes is known to vary greatly from different variety (Table 4.3). Comparison of amylose, RS, and dietary fibre in blends with different proportions, illustrated that differences were related to the composition and process of raw materials. Starch plays an important

role in the pasting properties of flour. The difference in the amylose/amylopectin ratio of starch results in the different gelatinisation properties of flour, which is related to the texture and quality of the final product. In general, lower amylose content corresponded to higher peak pasty viscosity and higher resilience. Wheat flour with high swelling power, high viscosity, low gelatinisation temperature, and high decomposition rate is ideal for high quality flour products (Van Hung, Maeda, & Morita, 2006).
Amylose content varies according to the source of starch (Tester, Karkalas, & Qi, 2004), in addition, amylose content has been shown to directly affect the gelatinisation of starch, which plays an important role in both the dough rheology and starch-based food processing (Schirmer *et al.*, 2013). Wheat flour has a higher amylose content than potato flour, so as potato flour was added, the amylose in the mixture decreased. The decrease of amylose in starch lead to an increase in the swelling of starch granules, which increases the peak viscosity of the paste but decreases the final viscosity of the pastes. Similar results have been observed in the grains (such as wheat and corn) (Gianibelli, Sissons, & Batey, 2005).

Compared to the RS of the wheat flour, the paste samples with added raw and cooked-frozen potato flour significantly increased the content of RS in the blends. Many studies have shown that RS has the physiological function of DF. Health benefits to consumers include reduced blood sugar and insulin responses to carbohydrate intake, increased absorption of vitamins and minerals, and act as prebiotics (Sajilata *et al.*, 2006). Therefore, it can be concluded that adding potato flour can increase RS content in the blends. Potato flour contained higher DF than wheat flour, which increased the dietary fibre content in the wheat and potato flour blends. RS and DF have been shown to have many nutritional properties and reduce the risk of disease (Brennan, 2005; Perera, Meda, & Tyler, 2010; Zhao *et al.*, 2018). In conclusion, compared with wheat flour, the blends with potato flour have higher nutritional value.

Table 5.1 Composition characteristics of wheat flour and its blend with Raw potato flours at 10%-50%.

Sample	Moisture %	Protein (%, g/100g)	Total starch (%, g/100g)	Amylose content (%, g/100g)	Resistant starch (%, g/100g)	SDF (%, g/100g)	IDF (%, g/100g)	TDF (%, g/100g)
Wheat	13.88 ± 0.13^{a}	13.42 ± 0.07^{a}	69.42 ± 0.43^{e}	27.56 ± 0.23^{a}	5.39 ± 0.11^{j}	1.58 ± 0.12^{f}	3.61 ± 0.21^{e}	5.19 ± 0.17^{gh}
RAF	7.84 ± 0.11^{h}	7.96 ± 0.04^{h}	77.76 ± 0.24^{a}	24.13 ± 0.14^{e}	45.25 ± 0.18^{a}	3.87 ± 0.08^{a}	5.53 ± 0.13^{a}	9.40 ± 0.05^{a}
RNF	8.69 ± 0.07^{g}	8.68 ± 0.01^{g}	70.18 ± 0.17^{b}	18.29 ± 0.15^{h}	42.05 ± 0.28^{b}	3.04 ± 0.15^{b}	3.55 ± 0.11^{e}	6.59 ± 0.12^{d}
10%RAF	13.01 ± 0.09^{b}	11.71 ± 0.12^{c}	73.53 ± 0.21^{d}	27.12 ± 0.14^{b}	8.43 ± 0.22^{i}	1.87 ± 0.14^{de}	3.76 ± 0.15^{e}	5.63 ± 0.16^{f}
20%RAF	12.75 ± 0.15^{b}	11.50 ± 0.12^{cd}	73.69 ± 0.12^{cd}	25.91 ± 0.17^{c}	12.46 ± 0.11^{g}	2.12 ± 0.21^{cd}	4.03 ± 0.13^{d}	6.15 ± 0.16^{e}
30%RAF	12.29 ± 0.09^{c}	11.01 ± 0.08^{ef}	74.05 ± 0.21^{c}	25.11 ± 0.16^{d}	16.28 ± 0.15^{e}	2.31 ± 0.12^{c}	4.62 ± 0.17^{c}	6.93 ± 0.14^{c}
40%RAF	11.65 ± 0.11^{e}	10.39 ± 0.12^{g}	74.59 ± 0.13^{bc}	24.35 ± 0.08^{e}	18.23 ± 0.11^{d}	2.83 ± 0.14^{b}	5.11 ± 0.21^{b}	7.94 ± 0.21^{b}
50%RAF	11.05 ± 0.07^{f}	10.16 ± 0.08^{g}	75.11 ± 0.09^{b}	23.80 ± 0.11^{f}	22.15 ± 0.08^{b}	2.92 ± 0.08^{b}	5.25 ± 0.11^{b}	8.17 ± 0.09^{b}
10%RNF	12.69± 0.09^{bc}	12.39 ± 0.12^{b}	70.69 ± 0.23^{cd}	27.17 ± 0.21^{ab}	8.31 ± 0.18^{i}	1.83 ± 0.14^{ef}	3.62 ± 0.05^{e}	5.45 ± 0.11^{gh}
20%RNF	12.75 ± 0.14^{b}	11.54 ± 0.11^{c}	70.72 ± 0.18^{cd}	25.52 ± 0.11^{cd}	11.89 ± 0.11^{h}	1.94 ± 0.11^{de}	3.66 ± 0.11^{e}	5.60 ± 0.10^{f}
30%RNF	12.97 ± 0.12^{b}	11.19 ± 0.16^{de}	71.13 ± 0.22^{bc}	24.51 ± 0.09^{e}	15.61 ± 0.14^{f}	2.05 ± 0.14^{cd}	3.65 ± 0.18^{e}	5.70± 0.16^{f}
40%RNF	12.35 ± 0.18^{c}	10.81 ± 0.11^{f}	71.24 ± 0.21^{bc}	23.46 ± 0.08^{f}	19.23 ± 0.14^{d}	2.23 ± 0.11^{c}	3.71 ± 0.16^{e}	5.94 ± 0.14^{e}
50%RNF	11.83 ± 0.13^{e}	10.47 ± 0.14^{g}	71.56 ± 0.25^{bc}	22.51 ± 0.13^{g}	22.89 ± 0.13^{c}	2.35 ± 0.07^{c}	3.70 ± 0.09^{e}	6.05 ± 0.09^{e}

10% Raw Agria potato Flour+90% wheat flour (10%RAF), 10% Raw Nadine potato flour+90% wheat flour (10%RNF), 20% Raw Agria potato flour+80% wheat flour (20%RAF), 20% Raw Nadine potato flour+80% wheat flour (20%RNF), 30% Raw Agria potato flour+70% wheat flour (30%RAF), 30% Raw Nadine potato flour+70% wheat flour (30%RNF), 40% Raw Agria potato flour+60% wheat flour (40%RAF), 40% Raw Nadine potato flour+60% wheat flour (40%RNF), 50% Raw Agria potato Flour+50% wheat flour (50%RAF), 50% Raw Nadine potato flour+50% wheat flour (50%RNF).

All measurements are mean values ± SD of triplicate determinations.

^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P< 0.05$; according to Tukey's test).

Table 5.2 Composition characteristics of wheat flour and its blend with Cooked potato flours at 10%-50%.

Sample	Moisture %	Protein (%, g/100g)	Total starch (%, g/100g)	Amylose content (%, g/100g)	Resistant starch (%, g/100g)	SDF (%, g/100g)	IDF (%, g/100g)	TDF (%, g/100g)
Wheat	13.83 ± 0.26^{a}	13.16 ± 0.18^{a}	69.16 ± 0.28^{d}	27.32 ± 0.15^{a}	5.39 ± 0.09^{a}	1.56 ± 0.17^{g}	3.60 ± 0.22^{de}	5.16 ± 0.18^{e}
CAF	8.57 ± 0.09^{i}	7.90 ± 0.02^{j}	77.88 ± 0.25^{a}	18.13 ± 0.14^{h}	4.40 ± 0.14^{b}	3.73 ± 0.08^{a}	5.59 ± 0.09^{a}	9.32 ± 0.08^{a}
CNF	9.05 ± 0.07^{i}	8.69 ± 0.01^{i}	70.14 ± 0.37^{cd}	14.18 ± 0.10^{i}	2.32 ± 0.11^{f}	3.09 ± 0.19^{b}	3.45 ± 0.13^{de}	6.54 ± 0.14^{bc}
10%CAF	13.15 ± 0.11^{b}	11.92 ± 0.08^{b}	70.95 ± 0.14^{c}	26.13 ± 0.17^{b}	4.46 ± 0.17^{b}	1.96 ± 0.17^{de}	4.12 ± 0.09^{bc}	6.08 ± 0.09^{c}
20%CAF	12.37 ± 0.12^{e}	11.43 ± 0.09^{cd}	71.09 ± 0.28^{c}	25.43 ± 0.15^{c}	4.12 ± 0.15^{bc}	2.11 ± 0.11^{cd}	4.03 ± 0.16^{c}	6.14 ± 0.13^{c}
30%CAF	12.19 ± 0.11^{ef}	10.73 ± 0.18^{ef}	71.66 ± 0.16^{bc}	24.51 ± 0.13^{d}	3.95 ± 0.14^{cd}	2.28 ± 0.15^{bc}	4.14 ± 0.13^{bc}	6.42 ± 0.14^{bc}
40%CAF	11.43 ± 0.07^{g}	10.19 ± 0.11^{gh}	72.45 ± 0.19^{bc}	23.49 ± 0.21^{e}	3.73 ± 0.12^{de}	2.51 ± 0.08^{bc}	4.35 ± 0.11^{bc}	6.86 ± 0.11^{c}
50%CAF	10.55 ± 0.12^{h}	9.86 ± 0.11^{h}	73.11 ± 0.18^{b}	22.39 ± 0.18^{f}	3.38 ± 0.18^{e}	2.78 ± 0.13^{b}	4.51 ± 0.16^{b}	7.29 ± 0.14^{b}
10%CNF	13.05 ± 0.07^{bc}	11.58 ± 0.08^{bc}	69.02 ± 0.14^{d}	26.09 ± 0.15^{b}	4.15 ± 0.09^{bc}	1.62 ± 0.11^{fg}	3.52 ± 0.12^{de}	5.14 ± 0.09^{e}
20%CNF	12.95 ± 0.12^{bc}	11.65 ± 0.09^{bc}	69.83 ± 0.16^{cd}	25.01 ± 0.14^{c}	4.12 ± 0.11^{bc}	1.86 ± 0.13^{ef}	3.53 ± 0.09^{de}	5.39 ± 0.12^{de}
30%CNF	12.76 ± 0.12^{cd}	11.27 ± 0.13^{d}	70.71 ± 0.11^{c}	23.71 ± 0.12^{e}	4.08 ± 0.09^{cd}	2.11 ± 0.11^{cd}	3.51 ± 0.14^{de}	5.62 ± 0.12^{d}
40%CNF	12.43 ± 0.07^{de}	10.89 ± 0.09^{e}	70.45 ± 0.15^{c}	22.54 ± 0.09^{f}	3.98 ± 0.08^{cd}	2.26 ± 0.09^{bc}	3.46 ± 0.11^{de}	5.72 ± 0.08^{d}
50%CNF	11.87 ± 0.12^{f}	10.48 ± 0.11^{fg}	70.91 ± 0.15^{c}	21.31 ± 0.14^{g}	3.86 ± 0.12^{cd}	2.37 ± 0.13^{bc}	3.42 ± 0.18^{de}	5.79 ± 0.12^{d}

10% Cooked Agria potato flour+90% wheat flour (10%CAF), 10% Cooked Nadine potato flour+90% wheat flour (10%CNF), 20% Cooked Agria potato flour+80% wheat flour (20%CAF), 20% Cooked Nadine potato flour+80% wheat flour (20%CNF), 30% Cooked Agria potato flour+70% wheat flour (30%CAF), 30% Cooked Nadine potato flour+70% wheat flour (30%CNF), 40% Cooked Agria potato flour+60% wheat flour (40%CAF), 40% Cooked Nadine potato flour+60% wheat flour (40%CNF), 50% Cooked Agria potato flour+50% wheat flour (50%CAF), 50% Cooked Nadine potato flour+50% wheat flour (50%CNF).

All measurements are mean values ± SD of triplicate determinations.

^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P < 0.05$; according to Tukey's

Table 5.3 Composition characteristics of wheat flour and its blend with Cooked-Frozen potato flours at 10%-50%.

Sample	Moisture %	Protein (%, g/100g)	Total starch (%, g/100g)	Amylose content (%, g/100g)	Resistant starch (%, g/100g)	SDF (%, g/100g)	IDF (%, g/100g)	TDF (%, g/100g)
Wheat	13.79 ± 0.16^{a}	13.32 ± 0.10^{a}	69.70 ± 0.18^{e}	27.51 ± 0.23^{a}	5.78 ± 0.10^{cd}	1.61 ± 0.05^{i}	3.52 ± 0.14^{h}	5.13 ± 0.13^{h}
CFAF	8.29 ± 0.11^{g}	8.10 ± 0.07^{g}	73.23 ± 0.24^{a}	19.23 ± 0.11^{h}	9.24 ± 0.11^{a}	3.77 ± 0.08^{a}	8.94 ± 0.11^{a}	12.71 ± 0.10^{a}
CFNF	8.27 ± 0.09^{g}	7.92 ± 0.05^{h}	64.25 ± 0.15^{h}	15.55 ± 0.12^{i}	4.51 ± 0.18^{f}	3.18 ± 0.22^{b}	8.36 ± 0.08^{b}	11.54 ± 0.22^{b}
10%CFAF	13.29 ± 0.14^{b}	12.18 ± 0.11^{b}	70.55 ± 0.13^{d}	26.85 ± 0.12^{b}	5.88 ± 0.15^{cd}	1.73 ± 0.12^{gh}	4.58 ± 0.17^{g}	6.31 ± 0.15^{g}
20%CFAF	13.17 ± 0.12^{bc}	11.47 ± 0.09^{c}	71.05 ± 0.18^{c}	26.01 ± 0.09^{c}	5.92 ± 0.16^{cd}	2.05 ± 0.09^{f}	5.13 ± 0.14^{f}	7.18 ± 0.11^{f}
30%CFAF	12.81 ± 0.13^{d}	10.99 ± 0.14^{d}	71.43 ± 0.15^{c}	24.63 ± 0.11^{d}	6.15 ± 0.09^{c}	2.26 ± 0.14^{e}	5.22 ± 0.11^{f}	7.48 ± 0.13^{e}
40%CFAF	12.34 ± 0.13^{e}	10.58 ± 0.12^{e}	72.01 ± 0.13^{b}	23.81 ± 0.18^{e}	6.16 ± 0.13^{c}	2.51 ± 0.11^{cd}	5.41 ± 0.13^{e}	7.92 ± 0.12^{d}
50%CFAF	11.55 ± 0.12^{f}	10.28 ± 0.13^{ef}	72.59 ± 0.15^{a}	22.85 ± 0.13^{f}	6.56 ± 0.14^{b}	2.73 ± 0.09^{c}	5.62 ± 0.09^{d}	8.35 ± 0.10^{c}
10%CFNF	13.37 ± 0.06^{b}	11.73 ± 0.12^{c}	71.93 ± 0.22^{b}	26.35 ± 0.21^{c}	5.41 ± 0.12^{i}	1.71 ± 1.14^{h}	5.16 ± 0.15^{f}	6.87 ± 0.18^{fg}
20%CFNF	13.17 ± 0.11^{bc}	11.56 ± 0.13^{c}	71.11 ± 0.16^{c}	25.01 ± 0.12^{d}	5.34 ± 0.12^{e}	1.84 ± 0.11^{g}	5.25 ± 0.12^{f}	7.09 ± 0.12^{f}
30%CFNF	12.83 ± 0.12^{cd}	11.01 ± 0.10^{d}	70.10 ± 0.12^{e}	23.96 ± 0.11^{e}	5.32 ± 0.11^{e}	2.02 ± 0.09^{f}	5.86 ± 0.15^{c}	7.88 ± 0.12^{d}
40%CFNF	12.26 ± 0.11^{e}	10.54 ± 0.13^{e}	69.14 ± 0.13^{f}	22.81 ± 0.14^{f}	5.25 ± 0.08^{e}	2.23 ± 0.07^{e}	5.92 ± 0.12^{c}	8.15 ± 0.09^{cd}
50%CFNF	11.59 ± 0.07^{f}	10.11 ± 0.12^{f}	68.12 ± 0.11^{g}	21.58 ± 0.14^{g}	5.19 ± 0.12^{e}	2.42 ± 0.11^{d}	5.95 ± 0.12^{c}	8.37 ± 0.12^{c}

10% Cooked-Frozen Agria potato flour+90% wheat flour (10%CFAF), 10% Cooked-Frozen Nadine potato Flour+90% wheat flour (10%CFNF), 20% Cooked-Frozen Agria potato flour+80% wheat flour (20%CFAF), 20% Cooked-Frozen Nadine potato flour+80% wheat flour (20%CFNF), 30% Cooked-Frozen Agria potato flour+70% wheat flour (30%CFAF), 30% Cooked-Frozen Nadine potato flour+70% wheat flour (30%CFNF), 40% Cooked-Frozen Agria potato flour+60% wheat flour (40%CFAF), 40% Cooked-Frozen Nadine potato flour+60% wheat flour (40%CFNF), 50% Cooked-Frozen Agria potato flour+50% wheat flour (50%CFAF), 50% Cooked-Frozen Nadine potato Flour+50% wheat flour (50%CFNF).

All measurements are mean values ± SD of triplicate determinations.

[a,b,c,d] Mean values within a column with unlike superscript letters are significantly different ($P < 0.05$; according to Tukey's test).

5.4.1.2 WSI, WAI, and SWC of gels of potato and wheat blends

The WSI, WAI and SWC of wheat and potato flour blends are summarised in Table 5.4-5.6. Water absorption has been considered as one of the most important functional properties of flour (Bushuk & Bekes, 2002). Tables 5.4-5.6 show that potato flour had higher WSI, WAI and SWC than wheat flour, the possible reason being that potato flour contains more hydrophilic components (such as soluble fibre), and starch was easier to gelatinise during heating, which improved the ability of starch to combine with water (Eliasson, 2017). Therefore, the WSI, WAI and SWC of the blends increased with the increase in the proportion of potato flour. Mangalika, Miura, Yamauchi, and Noda (2003) reported that low amylose starch granules rapidly swell when heated with excess water and subsequently exhibit a higher decomposition rate.

The solubility of flour or starch has been positively correlated with the reducing sugar content of flour after simulated *in vitro* digestion (Nuwamanya, Baguma, Kawuki, & Rubaihayo, 2008). The addition of potato flour increased starch digestion. When potato flour was mixed with wheat flour to make the dough, the gluten protein reduced, but the water absorption capacity of the dough increased, which would lead to a decrease in the stability of the dough, adversely affecting the production and processing.

The SWC reflects the ability of starch to gelatinise when combined with water during heating, compared with wheat flour, the SWC of blends was significantly increased. In the case of starch noodles, the restricted swelling behaviour of starches for noodle making is a desirable trait as limited swelling stabilizes starch against shearing action during cooking in water (Galvez & Resurreccion, 1992).

Table 5.4 WSI (water-soluble index), WAI (water absorption index), and SWC (swelling capacity) of wheat flour and its blend with Raw potato flours at 10%-50%.

Sample	WSI (g/100g)	WAI (g/g dry solids)	SWC (g/g dry solids)
Wheat	1.83 ± 0.04^{l}	2.13 ± 0.04^{i}	2.45 ± 0.06^{l}
RAF	10.03 ± 0.05^{a}	6.88 ± 0.04^{a}	5.37 ± 0.05^{a}
RNF	8.99 ± 0.06^{b}	6.62 ± 0.12^{b}	6.96 ± 0.08^{b}
10%RAF	2.65 ± 0.09^{k}	2.60 ± 0.11^{h}	2.95 ± 0.09^{k}
20%RAF	3.47 ± 0.05^{i}	3.08 ± 0.02^{g}	3.45 ± 0.04^{i}
30%RAF	4.29 ± 0.04^{g}	3.55 ± 0.04^{f}	3.96 ± 0.07^{g}
40%RAF	5.11 ± 0.06^{e}	4.03 ± 0.06^{e}	4.46 ± 0.05^{e}
50%RAF	5.93 ± 0.06^{c}	4.51 ± 0.05^{c}	5.05 ± 0.05^{c}
10%RNF	2.55 ± 0.06^{k}	2.58 ± 0.06^{h}	2.92 ± 0.05^{k}
20%RNF	3.26 ± 0.08^{j}	3.03 ± 0.05^{g}	3.39 ± 0.07^{j}
30%RNF	3.98 ± 0.03^{h}	3.48 ± 0.05^{f}	3.80 ± 0.06^{h}
40%RNF	4.70 ± 0.05^{f}	3.93 ± 0.04^{e}	4.33 ± 0.04^{f}
50%RNF	5.41 ± 0.06^{d}	4.38 ± 0.07^{d}	4.71 ± 0.06^{d}

10% Raw Agria potato Flour+90% wheat flour (10%RAF), 10% Raw Nadine potato flour+90% wheat flour (10%RNF), 20% Raw Agria potato flour+80% wheat flour (20%RAF), 20% Raw Nadine potato flour+80% wheat flour (20%RNF), 30% Raw Agria potato flour+70% wheat flour (30%RAF), 30% Raw Nadine potato flour+70% wheat flour (30%RNF), 40% Raw Agria potato flour+60% wheat flour (40%RAF), 40% Raw Nadine potato flour+60% wheat flour (40%RNF), 50% Raw Agria potato Flour+50% wheat flour (50%RAF), 50% Raw Nadine potato flour+50% wheat flour (50%RNF).
All measurements are mean values ± SD of triplicate determinations.
^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P < 0.05$; according to Tukey's test).

Table 5.5 WSI (water-soluble index), WAI (water absorption index), and SWC (swelling capacity) of wheat flour and its blend with Cooked potato flours at 10%-50%.

Sample	WSI (g/100g)	WAI (g/g dry solids)	SWC (g/g dry solids)
Wheat	1.86 ± 0.07^{l}	2.09 ± 0.02^{l}	2.41 ± 0.09^{m}
CAF	7.43 ± 0.09^{b}	9.64 ± 0.09^{a}	6.69 ± 0.08^{a}
CNF	7.01 ± 0.03^{a}	8.53 ± 0.09^{b}	7.66 ± 0.05^{b}
10%CAF	2.35 ± 0.02^{i}	2.88 ± 0.06^{k}	2.92 ± 0.05^{k}
20%CAF	2.87 ± 0.06^{h}	3.63 ± 0.05^{i}	3.39 ± 0.07^{j}
30%CAF	3.38 ± 0.03^{g}	4.38 ± 0.05^{g}	3.80 ± 0.06^{h}
40%CAF	3.95 ± 0.08^{e}	5.14 ± 0.04^{e}	4.33 ± 0.04^{f}
50%CAF	4.45 ± 0.04^{d}	5.89 ± 0.05^{c}	4.71 ± 0.06^{d}
10%CNF	2.38 ± 0.06^{i}	2.77 ± 0.08^{k}	2.95 ± 0.09^{k}
20%CNF	2.96 ± 0.06^{h}	3.41 ± 0.06^{j}	3.45 ± 0.04^{i}
30%CNF	3.51 ± 0.03^{f}	4.05 ± 0.05^{h}	3.96 ± 0.07^{g}
40%CNF	4.08 ± 0.07^{e}	4.69 ± 0.03^{f}	4.46 ± 0.05^{e}
50%CNF	4.61 ± 0.05^{c}	5.33 ± 0.05^{d}	5.05 ± 0.05^{c}

10% Cooked Agria potato flour+90% wheat flour (10%CAF), 10% Cooked Nadine potato flour+90% wheat flour (10%CNF), 20% Cooked Agria potato flour+80% wheat flour (20%CAF), 20% Cooked Nadine potato flour+80% wheat flour (20%CNF), 30% Cooked Agria potato flour+70% wheat flour (30%CAF), 30% Cooked Nadine potato flour+70% wheat flour (30%CNF), 40% Cooked Agria potato flour+60% wheat flour (40%CAF), 40% Cooked Nadine potato flour+60% wheat flour (40%CNF), 50% Cooked Agria potato flour+50% wheat flour (50%CAF), 50% Cooked Nadine potato flour+50% wheat flour (50%CNF). All measurements are mean values ± SD of triplicate determinations.

^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P < 0.05$; according to Tukey's test).

Table 5.6 WSI (water-soluble index), WAI (water absorption index), and SWC (swelling capacity) of wheat flour and its blend with Cooked-Frozen potato flours at 10%-50%.

Sample	WSI (g/100g)	WAI (g/g dry solids)	SWC (g/g dry solids)
Wheat	1.81 ± 0.07^{j}	2.14 ± 0.07^{i}	2.47 ± 0.09^{l}
CFAF	8.06 ± 0.08^{a}	5.88 ± 0.07^{a}	4.92 ± 0.07^{a}
CFNF	7.48 ± 0.02^{b}	5.58 ± 0.05^{b}	5.25 ± 0.09^{b}
10%CFAF	2.42 ± 0.02^{i}	2.49 ± 0.02^{h}	2.81 ± 0.07^{k}
20%CFAF	2.98 ± 0.06^{h}	2.88 ± 0.03^{g}	3.24 ± 0.03^{i}
30%CFAF	3.64 ± 0.03^{f}	3.26 ± 0.04^{f}	3.61 ± 0.05^{g}
40%CFAF	3.95 ± 0.08^{e}	3.63 ± 0.07^{d}	3.99 ± 0.06^{e}
50%CFAF	4.45 ± 0.04^{d}	3.99 ± 0.06^{c}	4.42 ± 0.07^{c}
10%CFNF	2.38 ± 0.06^{i}	2.48 ± 0.03^{h}	2.79 ± 0.05^{k}
20%CFNF	2.96 ± 0.06^{h}	2.85 ± 0.05^{g}	3.14 ± 0.07^{j}
30%CFNF	3.51 ± 0.03^{g}	3.14 ± 0.04^{f}	3.48 ± 0.06^{h}
40%CFNF	4.08 ± 0.07^{e}	3.52 ± 0.05^{e}	3.84 ± 0.04^{f}
50%CFNF	4.61 ± 0.05^{c}	3.87 ± 0.06^{c}	4.16 ± 0.05^{d}

10% Cooked-Frozen Agria potato flour+90% wheat flour (10%CFAF), 10% Cooked-Frozen Nadine potato Flour+90% wheat flour (10%CFNF), 20% Cooked-Frozen Agria potato flour+80% wheat flour (20%CFAF), 20% Cooked-Frozen Nadine potato flour+80% wheat flour (20%CFNF), 30% Cooked-Frozen Agria potato flour+70% wheat flour (30%CFAF), 30% Cooked-Frozen Nadine potato flour+70% wheat flour (30%CFNF), 40% Cooked-Frozen Agria potato flour+60% wheat flour (40%CFAF), 40% Cooked-Frozen Nadine potato flour+60% wheat flour (40%CFNF), 50% Cooked-Frozen Agria potato flour+50% wheat flour (50%CFAF), 50% Cooked-Frozen Nadine potato Flour+50% wheat flour (50%CFNF).
All measurements are mean values ± SD of triplicate determinations.
^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P < 0.05$; according to Tukey's test).

5.4.2 Pasting Properties of Wheat and Potato Flour Blends

Gelatinisation is the result of the interaction of starch and protein. The results of the pasting properties of wheat and potato flour blends were shown in Figure 5.1.

The peak viscosity (Figure 5.1 (a)), final viscosity (Figure 5.1 (b)), and setback (Figure 5.1 (c)) values of blends all showed a trend of gradually increasing with the increasing proportion of potato flour. Blennow, Bay-Smidt, and Bauer (2001) found that starch from potato tubers had a high viscosity, while that from sorghum and wheat had a relatively low viscosity. The difference between peak viscosity and final viscosity is small in starch with high amylose content, but the opposite is true for potato starch. Table 4.5 illustrated that potato flour had a high viscosity (Chapter 4), and these observations are supported by the report of Zaidul, Yamauchi, Kim, *et al.* (2007)

Figure 5.1 (a) shows the peak viscosity curves for the mixtures of wheat flour at 0-50% potato flour. There were significant differences in the peak viscosity between different treatments ($P < 0.05$). The peak viscosity was the highest in the cooked potato flour blends, followed by raw potato flour and cooked-frozen potato flour. Compared with raw potato flour, the gelatinisation process caused by cooking increased the viscosity of potato flour, while the high content of RS in cooked-frozen potato flour reduced the viscosity, this observation was similar to that reported in Chapter 4.

Agria had a higher peak viscosity than Nadine in the different types of potato flour blends, which could be attributed to the physicochemical properties of potato flour. The other reason for the wheat and potato flour blends having higher peak viscosity than wheat samples could be that the amylose decreased with the addition of potato flour (Table 5.1) in the blends. Reports have stated that amylose can prevent the starch particles from absorbing water, swelling, and gelatinisation (Blazek & Copeland, 2008), and amylose content has been shown to be inversely proportional to the swelling force (Tomoko Sasaki & Matsuki, 1998). Therefore, the addition of potato powder significantly enhanced the swelling capacity of the mixed flour, which is the expected feature in noodle products (Crosbie, 1991).

Figure 5.1 (b) and (c) show the final viscosity and setback curves for the mixtures of wheat flour at 0-50% potato flour, which represented the retrogradation characteristics of the sample. The value of the final viscosity always increased significantly with the increase of each potato starch in blends. The setback in the blends increased with the addition of potato flour, peaked at 20-30%, then tended to decrease and minimized at 50%. Zaidul, Yamauchi, Kim, *et al.* (2007) and Zaidul *et al.* (2002) observed on wheat-potato, and sago-wheat blends also support this conclusion. The setback represented the rearrangement of the amylose molecules excreted in the starch granules after swelling, which revealed the ability to gelation or retrogradation of amylose. Strong swelling forces tended to achieve maximum viscosity, but the intermolecular forces were weak, and they were more sensitive to shear forces as the temperature increased, so they decomposed easily (Ragaee & Abdel-Aal, 2006).

The breakdown represents the difference between the peak viscosity and the trough viscosity, and mainly reflects the thermal stability of starch, in that the higher the breakdown value, the worse the thermal stability of flour is (Odedeji & Adeleke, 2010).

The pasting temperature of the blends decreased with increases in the proportion of potato flour. Potato flour is easier to gelatinise than wheat flour, which is because potato flour does not contain gluten protein, which is also consistent with previous studies (Witczak, Ziobro, Juszczak, & Korus, 2016). In this study, substituting potato flour (10-30%) improved the water binding ability of the mixture. However, when the potato flour content increased to more than 40%, the starch granules were easily destroyed by shear forces, as shown in the gelatinisation and retrogradation observations. From this point of view, the addition of potato flour has an adverse impact on the quality of blends. Therefore, the added amount of potato flour should be controlled within a certain range (30% was the most appropriate maximum). Studies have shown that the peak viscosity, trough viscosity, and final viscosity influenced noodle products, showing a significant positive correlation (Crosbie, 1991).

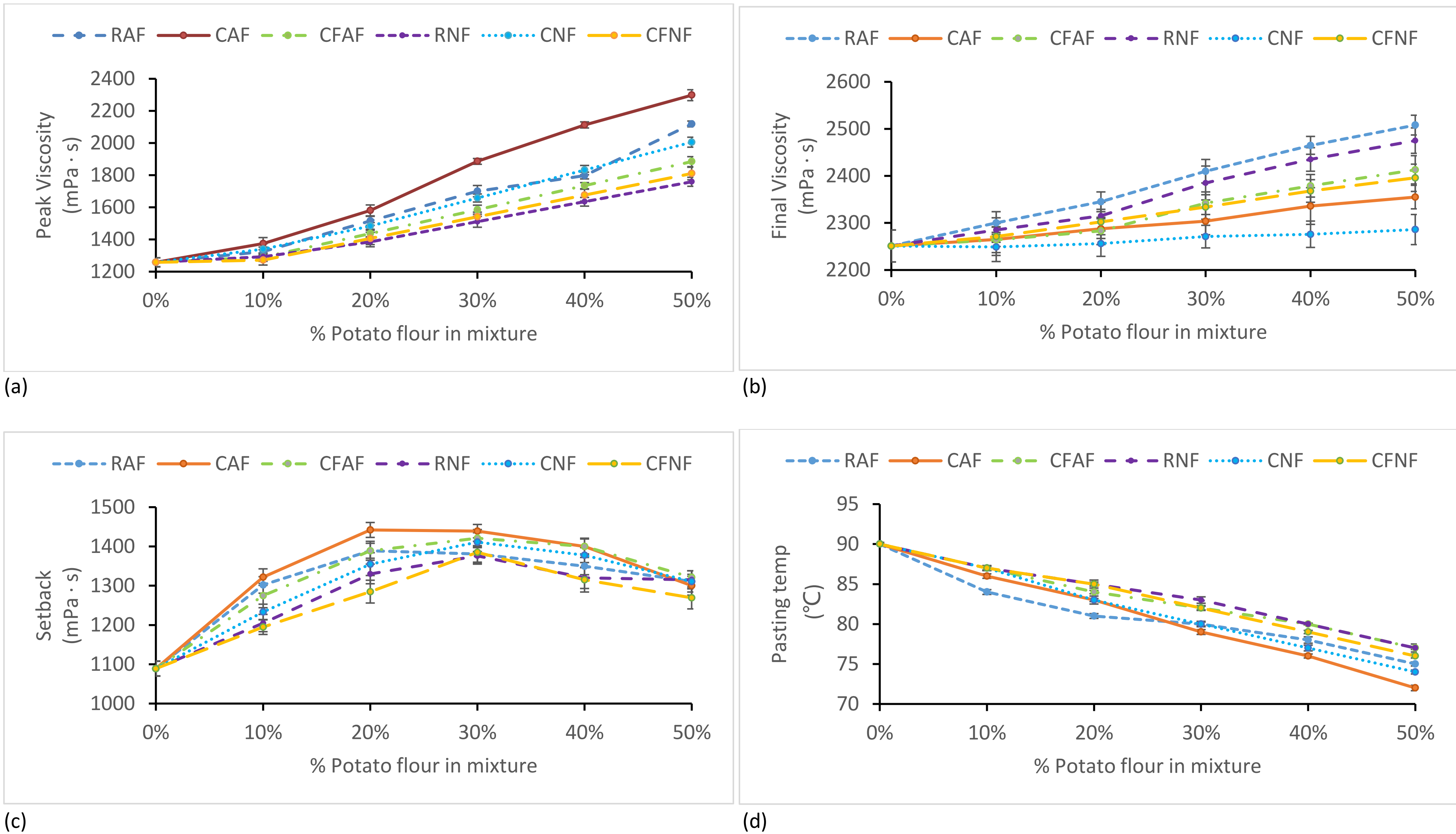


Figure 5.1 Pasting Properties of wheat flour and its blend with potato flours

The pasting properties of wheat flour and its blend with 10%-50% different potato flour. Peak viscosity (a), Final viscosity (b), Setback (c) and Pasting temp (d).

5.5 Conclusions

This study showed that the analysis of the functional and pasting characteristics of potato and wheat flour mixed with different proportions. It concluded that adding potato flour with different treatments significantly affected the performance of the blends ($p<0.05$). The functional and pasting characteristics of blends showed a trend change with the increasing of the potato flour.

The total starch, dietary fibre, amylose and RS gradually increased in the blends with the continuous increase of the proportion of potato flour. On the contrary, the moisture, protein, and amylose content decreased. The results of WSI, WAI, and SWC showed that the stability of dough and the quality of noodle products made by blends would be affected with the addition of potato flour. The peak viscosity, final viscosity and pasting temp increased with an increase in the potato flour from 10%-50%, and the results showed the added amount of potato flour should be controlled within a certain range.

This work encourages substituting potato flour for part of the wheat flour used in wheat-based food products. When the potato flour was added in the range of 20%-30%, the functional properties of blends the viscosity gradually increased. Further work is needed to determine the interaction between potato flour and wheat flour and application in food products and to explain their rheological properties using DSC and rheometer.

Chapter 6

Physicochemical and Textural Properties of Pasta Based on Wheat-potato Blends Flour

Abstract

In this chapter, semolina was replaced with two local cultivars of potato (Agria and Nadine) flour in pasta at 10%, 30% and 50% levels to make composite pasta products. The effects on the physicochemical properties (CL, WAI, SI and colour) and textural properties (firmness and extensibility) of the potato blend pasta samples were evaluated and compared to semolina pasta. Compared with durum wheat semolina pasta, the CL increased with the addition of potato flour, but decreased the SI and WAI of pasta samples. The addition of potato flour significantly increased the yellowness (b*) and decreased the brightness (L*) of the pasta compared with the control sample. Supplementation of potato flour also influenced the texture properties of potato-wheat pasta, the addition of potato flour increased the firmness and as the amount added increased to a maximum firmness, and then decreased at higher addition levels. An optimum level of 30% addition of potato flour was observed in terms of pasta quality. Thus, pasta based on wheat-potato blends flour has the potential to be a technological alternative for the food industry to provide nutritional enriched pasta products and promoted the processing of potato staple food.

6.2 Introduction

Potato (*Solanum tuberosum, L.*) is one of the world's major agricultural crops consumed by millions of people (Tian *et al.*, 2016). Potato is also rich in other nutrients that are required in the diet, such as vitamins and minerals (Burlingame *et al.*, 2009). In the food industry, raw potatoes are turned into potato flour involving processing through dehydration, in order to enhance the storage potential of potato. Typical dehydration of potato flour is achieved by heat or cooking, drying, grinding, and sieving production. Due to retaining the nutritional value and the function of starch gelatinisation, potato is industrially processed to a wide range of convenience products, the inclusion of potato flour instead of wheat flour in baking, extruded snacks and biscuits have been used to assess their sensory characteristics, nutritional value and flavour (Anupama & Kalpana, 2003; Nemar *et al.*, 2015; Singh *et al.*, 2009).

Pasta is the second most consumed staple food in the world, usually made of semolina from durum wheat and water (Marti & Pagani, 2013). Pasta is a popular food product because of its versatility, low cost, ease of preparation and nutritional quality (Foschia *et al.*, 2015a). Pasta is a healthy food which contains protein, vitamins and is an important source of carbohydrates with virtually no fat (Desai, Brennan, & Brennan, 2018; Foschia *et al.*, 2015a). The overall quality of pasta is determined by its cooking properties, textural characteristics and nutritional value. Specifically, cooking quality is the most important consumer attribute of pasta, including parameters such as CL, WAI, SI, and texture (Ficco *et al.*, 2016; Sobota, Rzedzicki, Zarzycki, & Kuzawińska, 2015). The quality of pasta, and cooking characteristics, are dependent upon the protein-starch network as well as the starch composition of the pasta product (Phongthai, D'Amico, Schoenlechner, Homthawornchoo, & Rawdkuen, 2017; Samaan *et al.*, 2006). In addition to this, the nutritional and functional properties of pasta play a significant role in its overall acceptability while the texture characteristics are possibly more important due to the impact, they have on consumer acceptance (Sobota *et al.*, 2015). Raw material composition used for the preparation of pasta product affects the physical, chemical and textural properties of pasta (Lu *et al.*, 2016).

Nowadays, in order to develop novel cereal-based product to enrich noodles, wheat noodles have been fortified with various ingredients. The main challenge is to provide the best product characteristics and ease of production without affecting structure and quality (Struck, Jaros, Brennan, & Rohm, 2014). Previous studies have investigated the effect of incorporating novel ingredients as non-durum wheat varieties, such as mushrooms (Lu *et al.*, 2016), fish powder (Desai, Brennan, & Brennan, 2018), dietary fibres (Foschia *et al.*, 2015a). These ingredients are gluten free. As a result, substituting these gluten free ingredients for wheat flour often negatively affects the quality of the noodles, including colour, texture and cooking properties. However, noodles with these ingredients are acceptable and can provide improved nutritional value (Pu *et al.*, 2017).

Therefore, the aim of this project was to develop pasta with improved nutritional properties by substituting semolina flour with potato flour at various concentrations and study the changes in nutritional, cooking colour and textural characteristics of the fresh pasta, in order to determine the possibility of producing wheat-based potato foods.

6.3 Materials and Methods

6.3.1 Raw Materials

Described in section 3.1

6.3.2 Preparation of Potato Flour

Described in section 3.1.1

6.3.3 Preparation of Pasta

Described in section 3.1.3 to 3.1.4

6.3.4 Cooking Procedure

Fresh pasta (100 g) was cooked in 600 mL boiling tap water for 6 min and strained for 30 s. Cooked pasta was then be analysed for cooking loss, swelling index, water absorption and textural properties (Lu *et al.*, 2016).

6.3.5 Cooking Loss

Described in section 3.3.2

6.3.6 Swelling Index and Water Absorption Index

Described in section 3.3.3

6.3.7 Colour Measurement

Described in section 3.3.5

6.3.8 Textural Characteristics

Described in section 3.3.4

6.4 Statistical Analysis

Described in section 3.4

6.5 Results and Discussion

6.5.1 Cooking properties of pasta

In order to understand how different amounts of potato flour affected product quality, the cooking properties of pasta with different potato/wheat flour ratios were measured. CL, SI and WAI can be used as a predictor of cooking performance for consumers and the industry as a whole (Pu *et al.*, 2017). Results obtained from these parameters are shown in Tables 6.1-3.

From Table 6.1, pasta with potato flour substitution showed a significant increase in CL compared with the wheat flour pasta, with the CL increasing proportional to the increase in potato flour content. This indicates that potato flour incorporation negatively affected the cooking quality of pasta. These results were in agreement with those from Pu *et al.* (2017), who reported an increase in cooking loss of potato noodles. In ordinary wheat noodle products, the double helix of amylopectin is destroyed during cooking, and amylose is leached from the starch granules. A stable protein gelatinised starch matrix can be formed, and cooking loss can be reduced. Compared to the control, the addition of potato flour resulted in the separation of starch from the gluten network during cooking treatment, which was regard as being caused by the weakening or destruction of the protein-starch matrix (Izydorczyk *et al.*, 2005). Previous research has illustrated that DF enriched pasta samples have a higher loss during cooking, possibly due to the destruction of the protein-starch continuum (Cleary & Brennan, 2006b). Comparing the two varieties of potato, no statistically significant difference was found in the effects of the three treatments on CL. However, the CL of all samples was below 8 g per 100 g, the value below which pasta quality was considered acceptable for the consumer (Foschia *et al.*, 2015b).

Table 6.1 Cooking loss (g/100g dry pasta) of pasta enriched with potato flour at 0%-50%.

Sample	RAF	CAF	CFAF	RNF	CNF	CFNF
Wheat	3.91 ± 0.03^{d}	3.91 ± 0.03^{d}	3.91 ± 0.03^{d}	3.91 ± 0.03^{d}	3.91 ± 0.03^{d}	3.91 ± 0.03^{d}
10%PF	4.52 ± 0.03^{c}	4.72 ± 0.04^{c}	4.85 ± 0.02^{c}	4.78 ± 0.02^{c}	4.89 ± 0.04^{c}	4.93 ± 0.02^{c}
30%PF	5.39 ± 0.03^{b}	5.15 ± 0.02^{b}	5.32 ± 0.03^{b}	5.49 ± 0.03^{b}	5.64 ± 0.02^{b}	5.49 ± 0.04^{b}
50%PF	6.47 ± 0.02^{a}	6.14 ± 0.03^{a}	6.02 ± 0.02^{a}	6.15 ± 0.03^{a}	6.07 ± 0.04^{a}	6.12 ± 0.02^{a}

10% potato flour+90% wheat flour pasta (10%PF), 30% potato flour+70% wheat flour pasta (30%PF), 50% potato flour+50% wheat flour pasta (50%PF).
All measurements are mean values ± SD of triplicate determinations.
^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P< 0.05$; according to Tukey's test).

Pasta will swell during cooking, which is mainly caused by the hydration of starch particles. The absorbed water will cause the pasta to swell. The SI of pasta, expressed as g water absorbed per g of dry pasta, depends on the type of ingredients in the pasta and their competitive ability to absorb and retain water in the cooked pasta. It is essential to observe this parameter because it determines whether the final cooked pasta is firm, elastic (forms a strong protein network), or slightly sticky and soft (significantly starchy swelling) (Bruneel, Pareyt, Brijs, & Delcour, 2010). Compared with the control pasta samples, when potato flour was added between 10-30%, the SI and WAI of the pasta samples were elevated (Table 6.2 and Table 6.3). This may be because the carboxyl and hydroxyl groups in the gel structure bind to readily available water, resulting in an increase in SI (Gull, Prasad, & Kumar, 2018).

High Si and WAI, together with low CL and good texture (high hardness and low viscosity), can be defined as high cooking quality (Bruneel *et al.*, 2010). The WAI was slightly increased due to the increased swelling force of pasta. The increase of the WAI may also be related to the decrease of amylose content (Tables 5.1-5.3), because the amylose has a higher water binding capacity (Sozer, Dalgıc, & Kaya, 2007).

Substituting potato flour for wheat flour at concentrations between 30-50% reduced the SI and WAI of the cooked pasta. Lee and Jung (2003) noted that the WAI of noodles during cooking was affected by the degree of starch gelatinisation and the hydration of proteins related to starch size. The fact that potatoes have less protein (Table 5.1-5.3), and a larger starch grain size than wheat may lead to higher WAI in potato noodles. This phenomenon can be attributed to the exposure of a large number of hydroxyl groups in potato flour, which is caused by the addition of gelatinised potato starch particles in the dough, thereby achieving more water interaction through hydrogen bonding (Pu *et al.*, 2017).

Compared to the control samples, the decrease of SI could be explained by the increase of DF content (Table 5.1-3). Dietary fibre and starch compete for water, starch usually absorbs less water and has less swelling capacity. This study was in line with previous research (Brennan & Tudorica, 2007; Chillo, Ranawana, & Henry, 2011). In addition, some studies have shown that when the concentration of DF (for instance inulin or beta-glucan) in pasta increases the SI decreases significantly (Aravind, Sissons, Fellows, Blazek, & Gilbert, 2012; Brennan, Kuri, & Tudorica, 2004). Competitive hydration of the fibre within the pasta matrix during cooking is reported to lead to restricted starch swelling (Tudorica *et al.*, 2002), and this could explain the lower swelling values obtained with higher level of addition of fibre sources to the potato pasta blends in our study.

Table 6.2 Swelling index (g water/g dry pasta) of pasta enriched with potato flour at 0%-50%.

Sample	RAF	CAF	CFAF	RNF	CNF	CFNF
Wheat	2.85 ± 0.02^{c}	2.85 ± 0.02^{d}	2.85 ± 0.02^{c}	2.85 ± 0.02^{cd}	2.85 ± 0.02^{d}	2.85 ± 0.02^{c}
10%PF	3.02 ± 0.04^{b}	3.15 ± 0.07^{b}	3.01 ± 0.03^{b}	3.03 ± 0.05^{b}	3.11 ± 0.03^{b}	2.96 ± 0.02^{b}
30%PF	3.26 ± 0.02^{a}	3.48 ± 0.01^{a}	3.23 ± 0.02^{a}	3.25 ± 0.03^{a}	3.34 ± 0.02^{a}	3.15 ± 0.01^{a}
50%PF	2.98 ± 0.03^{b}	3.17 ± 0.03^{b}	2.86 ± 0.02^{c}	2.89 ± 0.04^{cd}	3.03 ± 0.02^{c}	2.83 ± 0.02^{c}

10% potato flour+90% wheat flour pasta (10%PF), 30% potato flour+70% wheat flour pasta (30%PF), 50% potato flour+50% wheat flour pasta (50%PF).
All measurements are mean values ± SD of triplicate determinations.
^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P< 0.05$; according to Tukey's test).

Table 6.3 Water absorption index (g/100 g) of pasta enriched with potato flour at 0%-50%.

Sample	RAF	CAF	CFAF	RNF	CNF	CFNF
Wheat	79.42 ± 2.99^{b}	79.42 ± 2.99^{b}	79.42 ± 2.99^{b}	79.42 ± 2.99^{b}	79.42 ± 2.99^{b}	79.42 ± 2.99^{b}
10%PF	85.80 ± 2.16^{ab}	87.01 ± 2.32^{ab}	85.14 ± 2.43^{ab}	85.52 ± 2.15^{ab}	86.34 ± 2.08^{ab}	85.34 ± 2.19^{ab}
30%PF	92.81 ± 2.05^{a}	93.84 ± 2.53^{a}	92.11 ± 2.61^{a}	92.29 ± 1.19^{a}	93.22 ± 2.33^{a}	91.84 ± 2.54^{a}
50%PF	90.23 ± 3.13^{ab}	91.36 ± 2.92^{ab}	89.38 ± 1.92^{ab}	89.39 ± 1.42^{ab}	90.72 ± 2.22^{ab}	88.99 ± 2.14^{ab}

10% potato flour+90% wheat flour pasta (10%PF), 30% potato flour+70% wheat flour pasta (30%PF), 50% potato flour+50% wheat flour pasta (50%PF).
All measurements are mean values ± SD of triplicate determinations.
^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P< 0.05$; according to Tukey's test).

Among all the samples, the control pasta had the lowest DM, WAI and CL (Table 6.1 and Table 6.2). Compared with wheat flour pasta, the cooking loss of potato pasta in the cooking process was found to be within the acceptable range for consumers and industry (4%-7%). However, it is not desirable to significantly reduce the water absorption of pasta. For that reason, from the perspective of water absorption, it is recommended that the addition of potato flour should not exceed 30%.

6.5.2 Colour Measurement of Pasta

The colour of pasta is an important quality factor responsible for the consumer acceptance and influences the consumer can evaluate when selecting a product in the market (Carini, Vittadini, Curti, & Antoniazzi, 2009). The yellow colour of pasta is mainly due to the degradation of carotenoid pigments in the semolina. The colour intensity of pasta can be improved by adding some natural colour ingredients into the flour formula (Mirhosseini *et al.*, 2015). Adding potato flour at different ratios affected the L*, a* and b* values of pasta samples (Figure 6.1).

The effects of potato flour addition on L* value was dependent on both the variety, and the ratio added. As the amount of potato flour increased from 0 to 50% in wheat flours, the value of L* decreased (Figure 6.1 (a)). Similarly, Zhang, Sun, He, and Tian (2010) studied the effect of sweet potato flour on the colour characteristics of noodles and reported that the addition of sweet potato flour into noodles decreased the lightness (L*) value. The L* value usually reduced when other ingredients, such as potato juice (Kowalczewski *et al.*, 2015), fish powder (Desai, *et al.*, 2018), and soy flour (Collins & Pangloli, 1997) are incorporated into wheat flour to produce pasta or noodles. At the same potato flour addition levels, potato flour varieties, and the different treatments, had significant effects on brightness L* values ($P<0.05$). Agria potato flour was more likely to affect the L* value compared to the Nadine potato flour. Gelatinisation (the cooked potato flour) and further retrogradation (the cooked-frozen potato flour) reduced the L* value, which was more obvious with the addition of potato flour. Compared to the wheat flour control pasta, 10% of potato flour addition resulted in a decline in the L* value by the extents of 90.84, 90.80, 90.89, 90.90, 90.84 and 90.93 for RAF, RNF, CAF, CNF, CFAF and CFNF, respectively. However, comparing the 10% addition potato flour, at 50% of potato flour addition, the L* value declined by the extents of 2.24%, 1.78%, 1.76%, 1.52%, 2.27% and 1.57% for RAF, RNF, CAF, CNF, CFAF and CFNF, respectively. Previous research has suggested that the ideal value of L* in pasta is greater than 60, and the value of less than 50 indicates the overall darkness of the pasta (Charles *et al.*, 2007). In this work, the L* value of all cooked pasta with potato flour was over 60, L* parameters were acceptable for all samples.

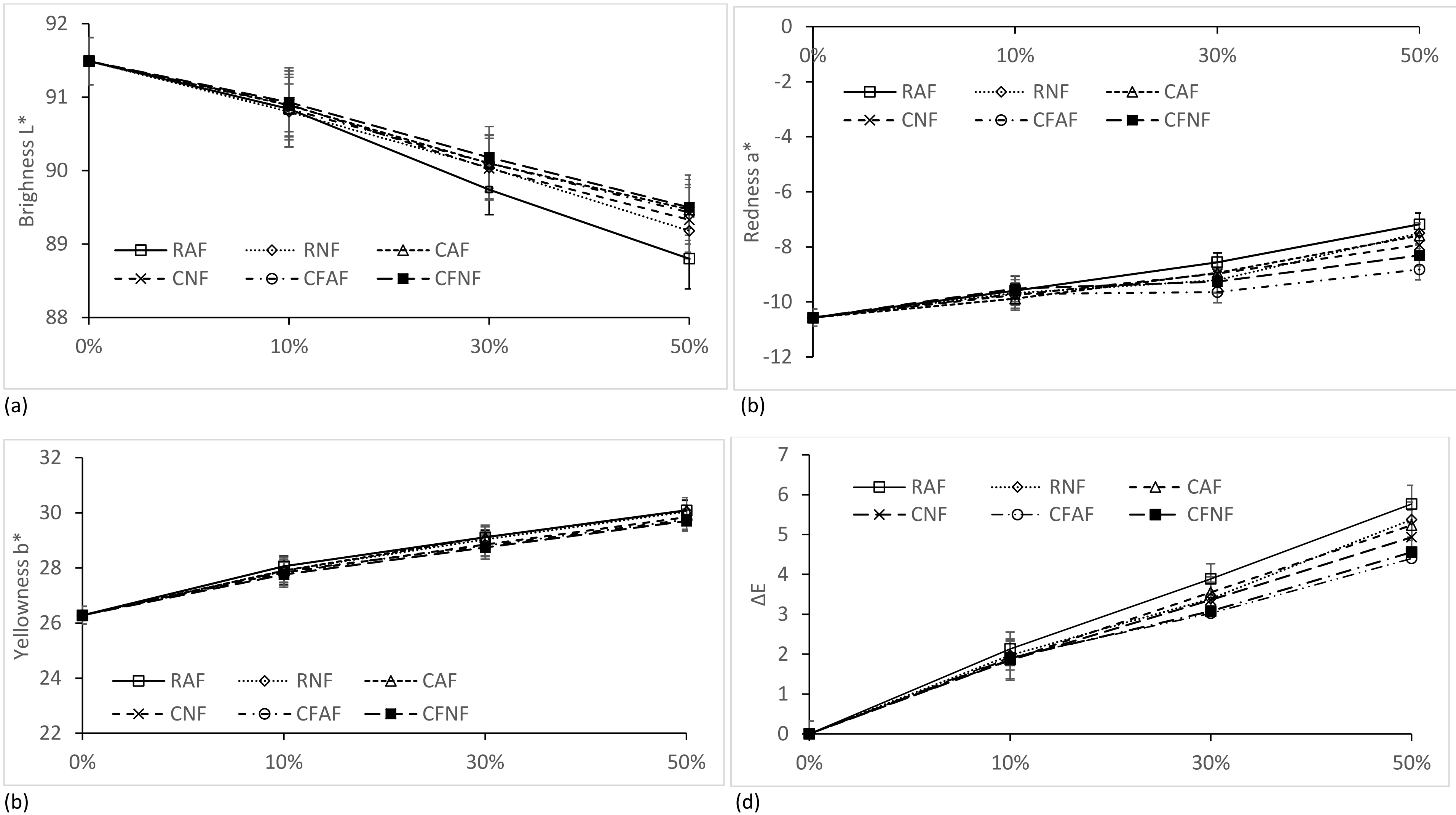


Figure 6.1 Colour characteristics of cooked pasta enriched with potato flours at 0%-50%.

As the amount of potato flour increased, there was significantly higher redness intensity in pasta, as indicated by increasing a value (Figure 6.1 (b)). The changing trends of a value in the respective control and potato pasta were similar. These results were in agreement with those from Alessandrini, Federica Balestra, Santina Romani, Pietro Rocculi, and Marco Dalla Rosa (2010) and Kowalczewski *et al.* (2015), who reported an increase in the red colour of pasta associated with the inclusion level of potato flour and potato juice. Comparing the different potato varieties, Agria potato flour affected the value of a*. In the same potato variety, the potato flour from different processing methods had a significant effect on the value of a*, and as the addition of potato flour, the effect on the value of a* become more obviously.

The yellowness b* values of sample were significantly different ($P<0.05$). Generally, a bright yellow colour pasta is more popular with consumers (Betoret, Betoret, Vidal, & Fito, 2011). As the amount of potato flour increased from 0 to 50% in wheat flours, the value of b* increasing (Figure 6.1 (c)). In this study, at 10% of potato flour addition, the b* values increased maximally, but it seemed that the b* values of potato pasta tend to be convergent or similar as potato flour addition increase. These results were in agreement with those from Zhang *et al.* (2010), who reported an increase in the yellowness of Chinese noodles based on wheat-sweet potato composite flour. The increase of b* value could be attributed to the direct influence of naturally occurring coloured components in SPF such as flavonoids, which increase with higher SPF content in the admixture (De Simone *et al.*, 2010). The interactions of non-wheat components with wheat components such as polyphenol oxidase (PPO) may result in yellow colour in noodles (Collins & Pangloli, 1997). Comparing different potato varieties, the different responses to potato pasta with the same potato flour addition levels might be due to combined effects of interaction between potato flour components and wheat flours blends (Pangloli, Collins, & Penfield, 2000).

When potato flour was added, the brightness (L *) decreased, while a * and b * values increased. The pasta gradually turned red and yellow. This was mainly because the whole potato powder was heat sensitive and high in sugar. When heated for a long time, the reducing sugar would combine with the protein to form the Maillard reaction product (Kolarič, Minarovičová, Lauková, Karovičová, & Kohajdová, 2019). The decrease in L* and the increase in a* and b* may be due to the yellow colour of potato flour compared to wheat flour (Nawaz *et al.*, 2019). The ΔE values were also determined to evaluate the colour differences between the control and the potato flour containing formulations. The ΔE values of potato flour pasta increased with increasing levels of potato flour in pasta.

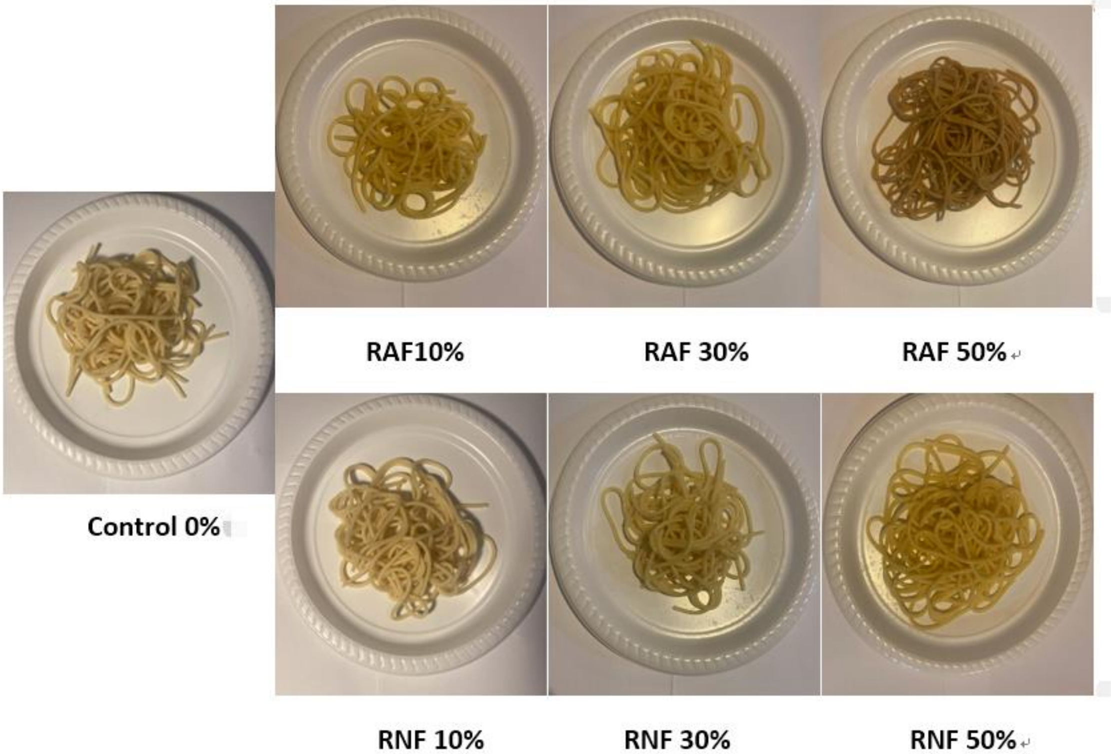


Figure 6.2 Images of pasta enriched with different levels of raw potato flour

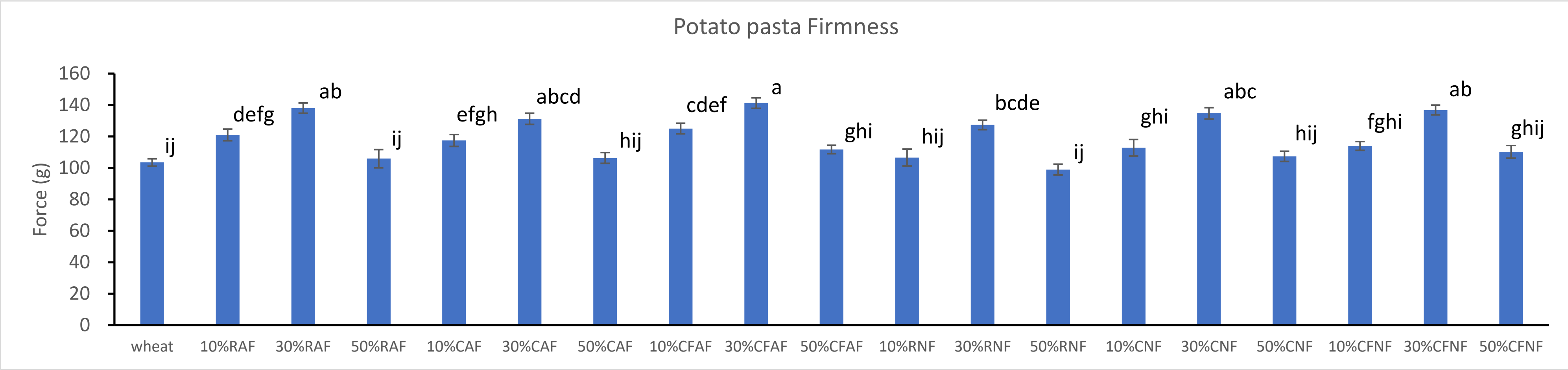
The total colour difference between the control sample and potato pasta, ΔE, was lower than five units, which suggests that by macroscopic observation, consumers could not see the apparent difference (Tazrart, Lamacchia, Zaidi, & Haros, 2016). The maximum ΔE by adding 50% of raw potato flour pasta, so the colour change of the visible light (Figure 6.2).

6.5.3 Texture Properties of Cooked Pasta

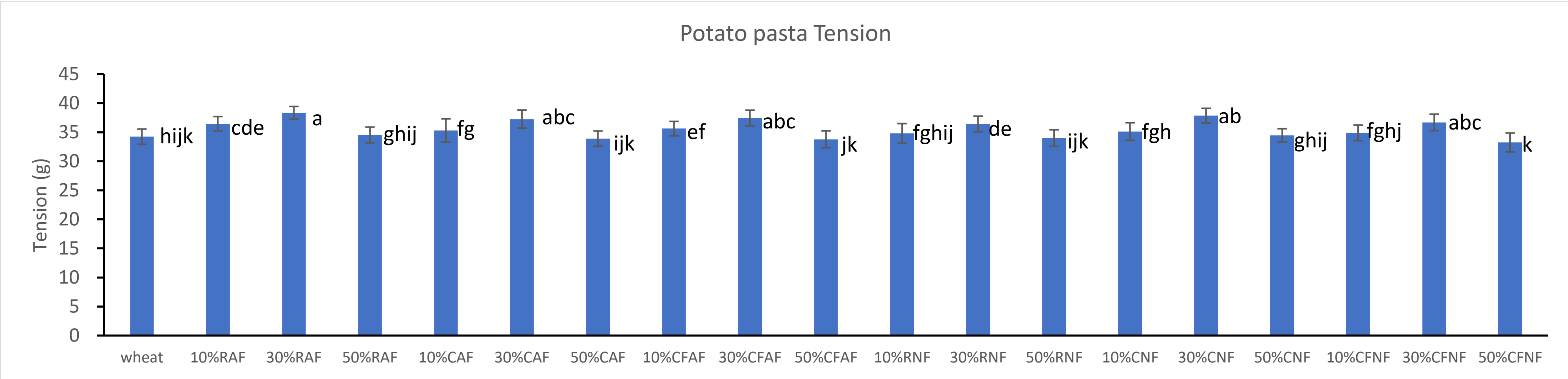
The texture of pasta is often considered the most important quality aspect of cooked pasta. From the consumer's perspective, high water absorption, low cooking loss, and good texture (high hardness and low viscosity) can be defined as high cooking quality (Andersen, Olsen, Carbonnel, Tjønneland, & Vogel, 2012). The texture of the cooked pasta was analysed by the Texture Analyser, and the results can be seen in Figure 6.3, which showed the firmness and tension properties of the two varieties of potato flour pasta. All samples were cooked for the same amount of time and then analysed. The addition of potato flour led to significant increases in firmness compared with the semolina pasta, this conclusion was consistent with Kowalczewski *et al.* (2015). Pu *et al.* (2017) found that when the addition amount of potato flour was between 0% and 40%, the parameters such as hardness, elasticity, and cohesion showed an overall increase with the addition of potato flour. This may be due to the interaction between the potato and wheat flour components, the presence of more gelatinised starch in the potato flour helped the blends to absorb water, resulting in increased adhesion (Linlaud, Puppo, & Ferrero, 2009). However, as the amount of addition continued to increase, the firmness began to decrease, and the firmness peaked at 30%. This may be due to the peak water swelling of the potato and wheat flour mixture (Figure 5.1 (c)), in which the amylose molecules are rearranged. The addition of potato flour weakens the gluten network, thereby reducing the hardness and disulphide bond of the pasta. Nawaz *et al.*, (2019) studied the effect of different proportions of potato flour on the rheological properties and structure of the instant noodle dough by replacing wheat flour with potato flour, and the results showed that the noodles deteriorated when the potato flour was more than 40%.

The effect of tension/elasticity of pasta on product structure showed the same trend as that of firmness. Comparing different types of potato flour, the processing method and potato variety had no significant effect on hardness and elasticity ($P>0.05$). Compared with the control sample, the elasticity increased first and then decreased with the influence of potato flour addition amount. The possible reason is that gluten gives wheat products good viscoelasticity, and the elasticity of noodles has a specific correlation with gluten content (Liu, He, Zhao, Pena, & Rajaram, 2003; Wieser, 2007).

It showed that adding a certain proportion of potato flour can enhance the texture of pasta, when the amount of potato flour added exceeded a certain range, the texture of pasta began to deteriorate.



(a)



(b)

Figure 6.3 Texture properties of cooked pasta enriched with different potato flour

All measurements are mean values ± SD of triplicate determinations.

[a,b,c,d] Mean values within a column with unlike superscript letters are significantly different ($P < 0.05$; according to Tukey's test).

6.6 Conclusions

In this study, semolina was replaced with two local cultivars of potato (Agria and Nadine) flour in pasta at 10%, 30% and 50% levels. The effects on the physicochemical properties (cooking loss, WAI, swelling index and colour) and textural properties (firmness and extensibility) of the potato pasta samples were evaluated compared with the semolina pasta. Compared with durum wheat semolina pasta, the cooking loss was significantly increased by adding potato flour, but further addition decreased the swelling index and water absorption. The addition of potato flour increased the yellowness (b*) and decreased the brightness (L*) of the pasta significantly compared to control sample. Moreover, supplementation of potato flour also influenced the texture properties of potato-wheat pasta, the addition of potato flour increased the firmness and as the amount added increased and then decreased, the potato flour pasta made with 30% had nice structure quality. Thus, pasta based on wheat-potato blends flour has the potential to be a technological alternative for the food industry to provide nutritional enriched pasta products and promoted the processing of potato staple food.

However, adding a certain percentage of potato flour can improve the quality of pasta. When the potato flour is added beyond a certain range, the quality of pasta begins to decline. Future research is needed to determine how the interaction between starch and protein in potato pasta affects pasta quality. Besides, the nutritional and functional analysis of potato pasta should be carried out to provide a reference for potato staple food.

Chapter 7

Effect of Potato Flour of Two Local Varieties on the Nutritional Quality of Pasta

Abstract

This study investigated the effect of substitution of durum wheat semolina with two local cultivars of potato (Agria and Nadine) flour on viscosity, digestion properties and the quality of pasta. Compared with durum wheat semolina pasta, the peak viscosity, final viscosity and setback were significantly increased by adding potato flour but decreased the pasting temperature. In addition, all enriched pasta with potato flour showed a significant increase in reducing sugar released during an *in vitro* digestion and standardised AUC values compared to control pasta. Fortification improved the pasting and nutrition of pasta products and promoted the processing of potato staple food.

7.2 Introduction

The rapid increase in lifestyle diseases have led to an increasing awareness among the consumers about the health benefits of new food products (Silva, Sagis, Van der Linden, & Scholten, 2013). Pasta is an excellent source of carbohydrates, low in sodium, low in fat and high in cholesterol, and is considered as one of important staple food of many countries. Traditionally, the primary ingredient of pasta is made from wheat semolina and water, as a food rich in complex carbohydrates with low GI is considered healthy and an ideal food to be enriched with nutrients (Silva *et al.*, 2013). Many studies have used different functional components to enhance the nutritional quality of pasta, such as mushroom powder (Lu *et al.*, 2018), dietary fibre (Foschia *et al.*, 2015b), fish protein (Desai, Brennan, *et al.*, 2018; Parvathy, Bindu, & Joshy, 2017), antioxidants (Jan, Saxena, & Singh, 2017), and other functional ingredients (Martínez, Marín, Gili, Penci, & Ribotta, 2017). Starch-based pasta is one of the most popular foods in worldwide, and potato starch plays an important role in the production of starch noodles (LaBell, 1990).

Potato (Solanum tuberosum, L.) is one of the world's major agricultural crops (Tian *et al.*, 2016). Potato is industrially processed into a wide range of convenience products, one of the main commercial products is potato flour, which is easy to store and circulate. The protein of potato flour is balanced in amino acid composition, and when combined with wheat flour it can improve protein quality, increase DF content and also improve of grain protein, and the content of vitamin and mineral elements. Potato flour contains several phytochemicals, such as polyphenols and flavonoids, which act as antioxidants and can fight cancer and hypertension (Ezekiel, Singh, Sharma, & Kaur, 2013). The inclusion of potato flour, instead of wheat flour, in baking, extruded snacks and biscuits has been used to assess their sensory characteristics, nutritional value and flavour, and novel dietary characteristics (Anupama & Kalpana, 2003; Nemar *et al.*, 2015; Singh *et al.*, 2009).

However, most research on potatoes has focused on starch, and little information is available about potato flour. Compared to wheat starch, potato starch has been reported to present lower phospholipids and to generate a starch paste with higher transmittance as well as large granule size, which has been used to produce several types of noodles (Noda *et al.*, 2006; Singh *et al.*, 2003). After cooking, potato noodles have been shown to have a clear appearance and a smooth texture (Sandhu & Kaur, 2010). The physicochemical and sensory properties of potato flour in pasta were studied to reveal the potential application of potato starch in producing pasta (Alessandrini *et al.*, 2010). Over the years, the research on noodles or pasta manufactured from wheat flour and potato starch mixes have focused on their product quality and properties such as their physicochemical, gel textural, pasting properties (Zaidul *et al.*, 2008; Zaidul *et al.*, 2007). At the same time, there have been many studies evaluating the glycemic response of pasta (Gao *et al.*, 2016; Lu *et al.*, 2018). However, little research has been carried out on the viscosity properties and digestion rate of potato-based products. Additionally, the importance of developing low GI potato-based pasta is possibly currently underestimated.

Starch is the main component of pasta (about 67%) and has different properties depending upon the botanical source of the starch. Therefore, it is important to correctly evaluate the changes caused by the effects of starch content, viscosity, and digestion in pasta. This study investigated the effect of substitution of durum wheat semolina with two local cultivars of potato (Agria and Nadine) flour on starch, viscosity, digestion properties and the quality of pasta. This research could spark interest in the use of potatoes and use flour for new product development and provide some useful guidance for potato product development.

7.3 Materials and Methods

7.3.1 Raw Materials

Described in section 3.1

7.3.2 Preparation of Potato Flour

Described in section 3.1.1

7.3.3 Preparation of Potato Pasta

Described in section 3.1.3 to 3.1.4

7.3.4 Pasting Properties of Pasta

Described in section 3.2.12

7.3.5 *In Vitro* Starch Digestibility and Glycemic Response

Described in section 3.3.6

7.4 Statistical Analysis

Statistical analysis was carried out as described in section 3.4

7.5 Results and Discussion

7.5.1 Total Starch, Amylose and Resistant Starch Determination of Cooked Pasta Enrich Potato Flour

The starch properties of blends flour and cooked pasta fortified with different potato flour levels are presented in Table 7.1.

Table 7.1 Starch properties of blends flour and cooked pasta fortified with different potato flour levels.

Sample	Blends flour sample			Cooked pasta Sample		
	Total starch (%, g/100g)	Amylose content (%, g/100g)	Resistant starch (%, g/100g)	Total starch (%, g/100g)	Amylose content (%, g/100g)	Resistant starch (%, g/100g)
Wheat	69.42 ± 1.09^{def}	27.56 ± 0.56^{a}	5.39 ± 0.09^{fg}	65.11 ± 1.11^{abc}	20.67 ± 0.36^{a}	4.72 ± 0.09^{e}
10%RAF	73.53 ± 1.11^{abc}	27.12 ± 0.46^{a}	8.43 ± 0.14^{d}	68.12 ± 1.21^{ab}	20.06 ± 0.09^{ab}	3.08 ± 0.12^{a}
30%RAF	74.05 ± 1.21^{ab}	25.11 ± 0.61^{bcde}	16.28 ± 0.11^{c}	68.23 ± 1.19^{ab}	18.33 ± 0.16^{fgh}	2.56 ± 0.08^{bc}
50%RAF	75.11 ± 0.98^{a}	$23.8 \pm 0.0.43^{efg}$	22.15 ± 0.17^{a}	68.34 ± 1.09^{a}	19.13 ± 0.11^{de}	2.03 ± 0.11^{de}
10%CAF	70.95 ± 1.21^{bcdef}	26.13 ± 0.46^{abcd}	4.46 ± 0.15^{hi}	65.97 ± 1.36^{abc}	19.34 ± 0.19^{cd}	2.83 ± 0.12^{ab}
30%CAF	71.66 ± 1.09^{abcde}	24.51 ± 0.47^{def}	4.08 ± 0.14^{ij}	65.95 ± 1.28^{abc}	17.89 ± 0.18^{ghij}	2.41 ± 0.11^{c}
50%CAF	73.11 ± 1.21^{abc}	22.39 ± 0.49^{gh}	3.86 ± 0.14^{ij}	66.02 ± 1.15^{abc}	18.17 ± 0.21^{ghi}	1.98 ± 0.06^{de}
10%CFAF	70.55 ± 1.21^{cdef}	26.85 ± 0.42^{ab}	5.88 ± 0.09^{efg}	65.73 ± 1.12^{abc}	19.60 ± 0.23^{bcd}	2.94 ± 0.12^{a}
30%CFAF	71.43 ± 1.14^{bcdef}	24.63 ± 0.39^{cde}	6.15 ± 0.27^{ef}	65.89 ± 1.11^{abc}	17.73 ± 0.18^{hijk}	2.47 ± 0.10^{c}
50%CFAF	72.59 ± 1.21^{abcd}	22.85 ± 0.61^{fgh}	6.56 ± 0.12^{e}	66.37 ± 1.21^{ab}	18.54 ± 0.14^{efg}	2.01 ± 0.11^{de}
10%RNF	70.69 ± 0.95^{bcdef}	27.17 ± 0.52^{a}	8.31 ± 0.14^{d}	65.71 ± 1.12^{abc}	19.83 ± 0.23^{bc}	2.12 ± 0.09^{d}
30%RNF	71.13 ± 0.99^{bcdef}	24.51 ± 0.51^{def}	15.61 ± 0.11^{c}	65.84 ± 1.10^{abc}	17.64 ± 0.34^{ijk}	1.94 ± 0.07^{de}
50%RNF	71.56 ± 1.11^{bcdef}	22.51 ± 0.16^{gh}	20.89 ± 0.17^{b}	66.04 ± 1.05^{ab}	18.98 ± 0.24^{def}	1.83 ± 0.09^{d}
10%CNF	69.92 ± 0.99^{ef}	26.09 ± 0.51^{abcd}	4.15 ± 0.09^{ij}	65.12 ± 1.21^{abc}	19.04 ± 0.16^{de}	2.11 ± 0.12^{d}
30%CNF	70.71 ± 1.05^{bcdef}	23.71 ± 0.53^{efg}	3.95 ± 0.33^{ij}	65.22 ± 1.31^{abc}	17.07 ± 0.17^{k}	1.91 ± 0.15^{de}
50%CNF	70.91 ± 1.09^{bcdef}	21.31 ± 0.52^{h}	3.38 ± 0.12^{j}	64.85 ± 1.22^{abc}	18.13 ± 0.21^{ghij}	1.79 ± 0.08^{e}
10%CFNF	71.93 ± 1.05^{abcde}	26.35 ± 0.71^{abc}	5.41 ± 0.09^{fg}	64.19 ± 1.31^{c}	19.49 ± 0.09^{bcd}	2.12 ± 0.04^{d}
30%CFNF	70.1 ± 1.48^{cdef}	23.96 ± 0.23^{efg}	5.32 ± 0.31^{fg}	64.68 ± 1.14^{bc}	17.49 ± 0.31^{jk}	1.92 ± 0.06^{de}
50%CFNF	69.75 ± 1.22^{f}	21.58 ± 0.29^{h}	5.19 ± 0.12^{gh}	65.39 ± 1.09^{abc}	18.22 ± 0.22^{ghi}	1.82 ± 0.09^{d}

All measurements are mean values ± SD of triplicate determinations.
a,b,c,d Mean values within a column with unlike superscript letters are significantly different ($P < 0.05$; according to Tukey's test).

In this work, the effects of potato flour addition on the contents of total starch, amylose, and RS in pasta products were analysed, as shown in Table 7.1. This difference between the flour and pasta samples may be due to the fact that certain ingredients of the pasta are leached out of the dough during cooking.

The total starch content in pasta products was determined (Table 7.1). The addition of potato flour increased the starch content in the mixture and pasta. Liu *et al.* (2016) added potato flour to wheat flour to make steamed bread, found that when the amount of potato flour increased from 0 to 35%, the starch content increased from 60.49 to 64.38%. After cooking, the total starch content level in pasta decreased slightly due to higher cooking loss compared to the total starch content in the mixture. Total starch loss increased with the addition of potato flour. This observation is consistent with the increase in cooking loss. Kolarič *et al.* (2019) found the same observation by studying the pasta enriched with sweet potato starch. The addition of sweet potato starch led to a decrease in the total starch content of the pasta after cooked. In contrast, the addition of sweet potato starch did not significantly change the total starch content.

The amylose content of wheat flour was higher than that of potato flour, and the addition of potato flour reduced the amylose content in the mixture. This may make potato flour addition an ideal choice for higher digestibility (Riley, Wheatley, & Asemota, 2006). Compared with wheat flour pasta, when the proportion of potato flour added was between 10% and 30%, the amylose content of the potato-fortified pasta decreased. This may be related to the loss of amylose during cooking (Pinhero *et al.*, 2016). However, further substituting potato flour for wheat flour (30-50%) increased the amylose content in cooked pasta. Pu *et al.* (2017) studied the effects of the potato flour/wheat flour ratio on the mixture characteristics of the dough and the quality of the noodles and confirmed that the amount of potato added would affect the starch network in the dough and noodles. During the heating process, the dissolution and crystallization of amylose affect the content of amylose.

The cooking process reduced the RS content in the mixture. The main reason for the low RS content in the cooked samples was the gelatinisation of starch, followed by possible loss of the RS in the cooking water. In food heated in the presence of water, starch particles swell, and amylose leaches out. This can make the starch in the food easier to digest, so cooked pasta contains less RS (Sharma, Yadav, & Ritika, 2008). Another reason for the decrease in RS content could be the activity of α-amylase. By increasing the temperature, the hydrolysis process of starch was enhanced due to the increase of α-amylase activity (Mironeasa, Codina, & Mironeasa, 2012). The RS of pasta fortified with potato flour decreased with potato flour added (Table 7.1). Therefore, it can be concluded that adding potato flour can decrease RS content in pasta.

The total starch content, amylose content, and RS content of potatoes with different varieties and processing methods were compared by referring to the same addition amount of potato flour. Taking all things into consideration, the pasta enriched with Agria potato flour had a high content of total starch, the RS, and amylose content after cooking than the control pasta. These properties will affect the blood glucose level, and we will further study its digestive properties.

7.5.2 Pasting Characteristics of Cooked Pasta Fortified with Potato Flour

The gelatinisation properties of starch determine the processing and storage properties of the product. The ungelatinized starch particles are mainly in the form of microcrystalline grains, which are connected by hydrogen bonds in the middle (Javaid *et al.*, 2018). After heating, the structure of starch begins to be damaged, first by loss of crystal structure, then by starch swelling, when amylose molecules begin to precipitate to form the leading network (Mudgil, Barak, & Khatkar, 2016).

The RVA test is widely used to assess viscosity changes in cereal powder or starch during heating and cooling. In general, the gelatinisation properties are related to the expansion and rupture of starch particles in the system, and the viscosity of the gelatinisation depends on the swelling amount (Nawaz *et al.*, 2019). Table 7.2 shows the RVA characteristic values of potato flour products enriched with different contents. With the increase of potato flour, the peak viscosity fluctuates and reaches the highest value when the additive amount reaches 30%. The valley viscosity and breakdown increased with the amount of potato flour added. However, the final viscosity values decreased with the increase of potato flour.

The peak viscosity indicates the ability of the sample to bind to water. The peak viscosity first increased and then decreased, probably due to the addition of between 0% and 30%, pasta enriched with potato flour still forms a gluten network due to the protein content of potato flour. Potato flour contains protein but not in the form of gluten (Bártová *et al.*, 2015). Further addition of potato flour weakened the starch - gluten network, which reduced the concentration of gluten protein. Similarly, Liu *et al.* (2016) reported that the addition of potato flour disrupted the gluten network and changed the viscoelastic properties of the dough, indicating the change in the rheological properties of the pasta enrich potato flour through changes in the microstructure. The potato flour increased the viscosity of the potato starch-wheat gluten mixture, while the presence of gluten reduced the viscosity of the sample. Similar results have been observed in previous studies (Xu et al., 2020). This may be due to the hydrophilic property of gluten, its strong ability to absorb water reduces the water used in swelling and gelatinization of potato starch.

The breakdown reflects the sensitivity of cooked starch to collapse easily during heating and the stability of hot starch paste. With the increase of wheat gluten content, the breakdown significantly decreases. This effect was not observed in the potato starch - wheat gluten composite pastes. The setback viscosity is related to the retrogradation and rearrangement of starch molecules. A low setback value indicates a low rate of starch regrowth and dehydration shrinkage. It may be that with the increase of potato flour content in the treatment, the increase of fibre content may help to reduce the paste viscosity. Fibre is thought to promote the absorption of starch particles, thereby affecting the rearrangement of starch molecules.

Many researchers have reported the effect of potato starch on the increase, or decrease, of paste viscosity. Zaidul *et al.* (2007) studied the pasting characteristics of wheat flour and potato starch mixtures with different amylose contents. The researchers found that the peak viscosity, setback, final viscosity, and the peak time of potato starch was higher than that of wheat flour. The peak viscosity increased significantly with the increase of potato starch in the mixture. Nawaz *et al.* (2019) studied the substitution of five different levels of potato flour for wheat flour, and the results showed that the gelatinisation properties such as peak viscosity, viscosity, decomposition, and final viscosity decreased with the addition of potato flour.

Comparing the results shown in Table 7.2, at different potato varieties and treatments the viscosity of pasta enriched in Nadine potato flour was significantly lower than that of Agria. This could be explained by the low starch content of Nadine. These results were attributed to the addition of potato flour, which destroyed and changed the chemical composition of the mixture.

Table 7.2 Pasta characteristics of cooked pasta fortified with different potato flour levels

Sample	Peak Viscosity (mPa · s)	Trough Viscosity (mPa · s)	Breakdown Viscosity (mPa · s)	Final Viscosity (mPa · s)	Setback (mPa · s)	Pasting Temp (℃)
Wheat	1532 ± 15^{fg}	762 ± 18^{bcd}	770 ± 21^{e}	1723 ± 21^{a}	961 ± 19^{a}	68 ± 0.95^{abc}
10%RAF	1562 ± 21^{ef}	771 ± 21^{bcd}	790 ± 24^{cde}	1683 ± 22^{a}	911 ± 13^{ab}	67 ± 0.64^{abc}
30%RAF	1622 ± 19^{abcd}	790 ± 23^{abcd}	831 ± 25^{bcde}	1603 ± 24^{bcd}	812 ± 21^{cd}	66 ± 0.86^{cde}
50%RAF	1599 ± 12^{bcde}	809 ± 17^{abc}	872 ± 21^{ab}	1523 ± 23^{ef}	714 ± 24^{e}	65 ± 0.67^{e}
10%CAF	1574 ± 24^{cdef}	779 ± 29^{bcd}	795 ± 24^{cde}	1656 ± 27^{ab}	876 ± 21^{b}	70 ± 0.94^{a}
30%CAF	1659 ± 18^{a}	814 ± 24^{abc}	845 ± 11^{abc}	1522 ± 23^{ef}	708 ± 20^{e}	69 ± 0.56^{ab}
50%CAF	1634 ± 17^{ab}	849 ± 19^{a}	895 ± 24^{a}	1389 ± 26^{ij}	540 ± 26^{f}	68 ± 0.83^{ab}
10%CFAF	1547 ± 26^{ef}	764 ± 24^{bcd}	782 ± 20^{de}	1666 ± 28^{ab}	902 ± 16^{ab}	68 ± 0.64^{ab}
30%CFAF	1576 ± 24^{bcdef}	768 ± 21^{bcd}	807 ± 19^{cde}	1552 ± 29^{def}	784 ± 18^{d}	67 ± 0.83^{abc}
50%CFAF	1528 ± 16^{fg}	772 ± 27^{bcd}	833 ± 17^{abcd}	1439 ± 24^{ghi}	667 ± 24^{e}	66 ± 0.79^{cde}
10%RNF	1548 ± 21^{ef}	766 ± 23^{bcd}	781 ± 22^{de}	1673 ± 23^{ab}	907 ± 26^{ab}	66 ± 0.86^{cde}
30%RNF	1579 ± 16^{bcdef}	774 ± 24^{bcd}	804 ± 24^{cde}	1575 ± 26^{cde}	801 ± 19^{d}	64 ± 0.91^{ef}
50%RNF	1487 ± 12^{gh}	782 ± 28^{abcd}	828 ± 19^{bcde}	1477 ± 27^{def}	694 ± 21^{e}	62 ± 0.79^{f}
10%CNF	1565 ± 13^{def}	774 ± 16^{bcd}	790 ± 21^{cde}	1650 ± 27^{ab}	875 ± 22^{bc}	67 ± 0.89^{abc}
30%CNF	1631 ± 27^{abc}	800 ± 22^{abcd}	831 ± 17^{bcde}	1504 ± 26^{efg}	704 ± 24^{e}	67 ± 0.83^{abc}
50%CNF	1565 ± 14^{bcdef}	825 ± 18^{ab}	873 ± 20^{ab}	1359 ± 23^{j}	533 ± 20^{f}	66 ± 0.95^{cde}
10%CFNF	1533 ± 19^{fg}	757 ± 21^{cd}	775 ± 13^{de}	1660 ± 28^{ab}	903 ± 12^{ab}	67 ± 0.93^{abc}
30%CFNF	1535 ± 22^{fg}	748 ± 20^{cd}	787 ± 22^{cde}	1536 ± 24^{def}	788 ± 23^{d}	66 ± 0.81^{cde}
50%CFNF	1454 ± 20^{h}	739 ± 17^{d}	798 ± 11^{cde}	1412 ± 29^{hij}	673 ± 15^{e}	65 ± 0.67^{de}

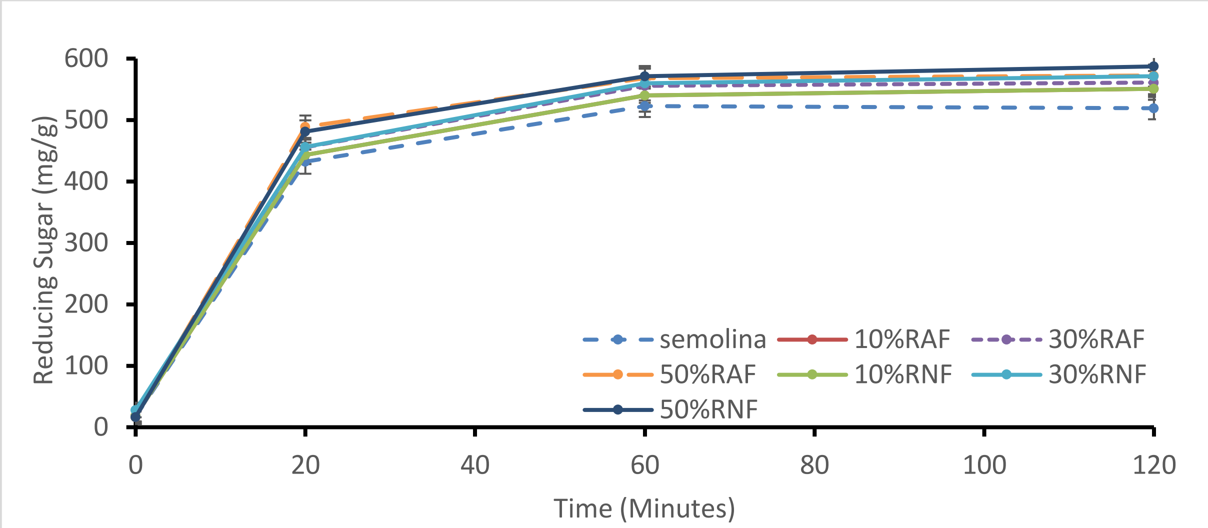
All measurements are mean values ± SD of triplicate determinations.
a,b,c,d Mean values within a column with unlike superscript letters are significantly different ($P < 0.05$; according to Tukey's test).

7.5.3 *In vitro* method for predicting glycemic response digestion of pasta fortified with potato flour

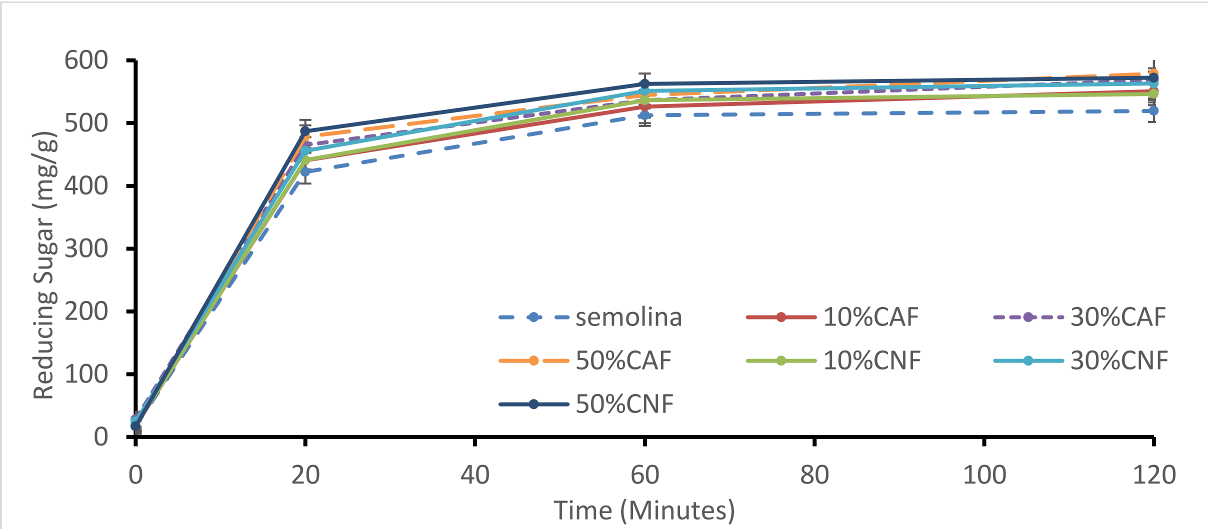
Pasta is a traditional product regarded as a medium or low glycemic food, due to its characteristic property of slow release of glucose into the system. However, potato has been reported as a medium to high glycemic food, with a GI of>55 (García-Alonso & Goñi, 2000). Potato varieties, maturity level, starch structure, food processing techniques and composition of the meal contribute to the GI of potato (Nayak, Berrios, & Tang, 2014). *In vitro* starch digestibility was monitored from 20 to 120 min for the sample formulations from the two varieties, and *in vitro* digestibility values for the pasta samples are shown in Fig. 7.1 a; b and c, representing an interpretation of the amount of reducing sugars released over a 120 min *in vitro* digestion of each pasta sample. It was noticeable that there was a significant difference between the semolina pasta and potato pasta. In all samples, the values of reducing sugars increased dramatically in the first 20 min and the peak values were reached between 20 min and 60 min. The release of reducing sugars was lower in the control pasta samples compared to all the potato flour pasta samples (Fig. 7.1 a.b.c). Pasta containing 50% potato flour released the most reducing sugar. Cao, Zhang, Guo, Dong, and Li (2019) illustrated that fast-digested starch was related to the expected GI of steamed bread, and that bread produced using wheat flour substituted with 0%–50% potato pulp, decreased from 87.81% to between 46.98% to 31.40%. The digestibility of starch depends on the structural properties of starch (gelatinisation, particle size, amylose/amylopectin ratio, and molecular structure), food processing or storage conditions, and the presence of other food ingredients in starchy foods (Jaspreet Singh, Dartois, & Kaur, 2010).

In this study, the addition of potato flour into pasta led to an increase in the AUC reducing sugars levels. For instance, the AUC values in pasta enriched with potato flour increased gradually with the increase of potato flour added (Fig. 7.2 a.b.c). As shown in Fig. 7.2, the largest increase in reducing sugars released for all pasta samples occurred in the first 20 min (the RDS fraction). The SDS fraction is digested after the RDS (Englyst *et al.*, 1992). From Fig. 7.2, it is clear that there was a transition in the smoothness of the digestion curves, showing the change in reducing sugar production from RDS to SDS. For potato flour pasta, there was an increase in reducing sugar release between 20 to 60 min, the growth trend was much slower than that of the first 20 min, while the curves between 60 to 120 min were nearly horizontal.

For raw potato flour and cooked potato flour pasta, the increase in reducing sugar levels were much quicker than that of semolina pasta between 0 to 20 min, while cooked-frozen was slower than that of semolina pasta. This indicates the possibility of different SDS contents in the three different treatment potato flour, although further work needs to be conducted to establish the exact relationship of RDS and SDS to sugar release in these samples. The difference in the digestibility of starch was attributed to the composition of starch. It is well known that the action of amylase is prevented by the esterified phosphate group attached to the glucose residue of the starch, so the complete hydrolysis of the starch with the phosphate group produces phosphoryl-oligosaccharides (Noda *et al.*, 2008). In theory, starch enriches in phosphate groups shows lower enzyme digestibility. Englyst, Vinoy, Englyst, and Lang (2003) reported that potato starch contained resistant starch and dietary fibre, which caused satiety and produced low blood sugar and insulin responses in the body, these effects promote weight control and control in patients with type 2 diabetes. Therefore, the addition of potato flour within a certain range has the potential as a healthy diet choice



(a)



(b)

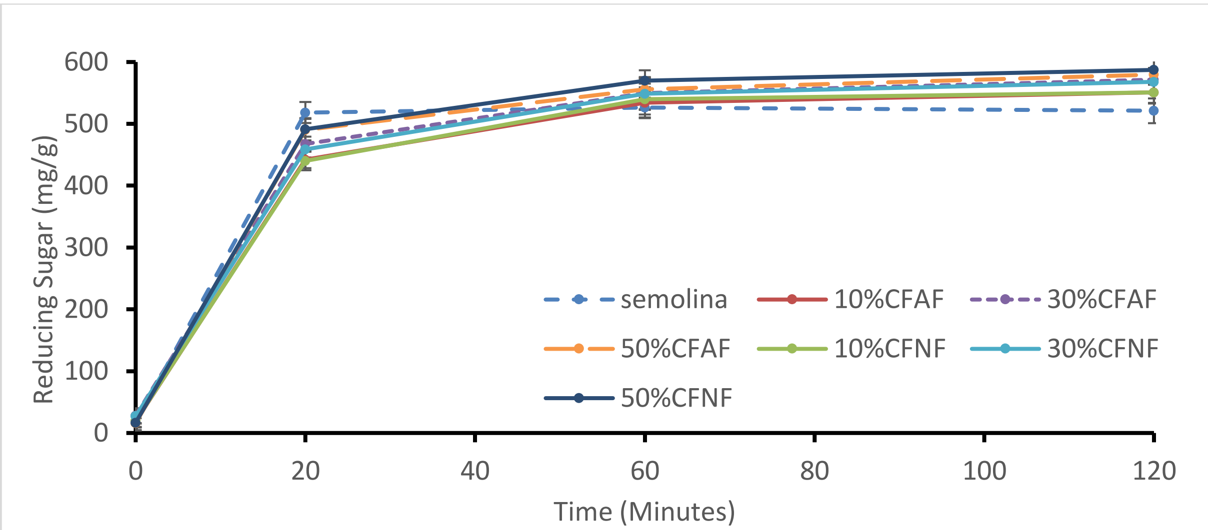
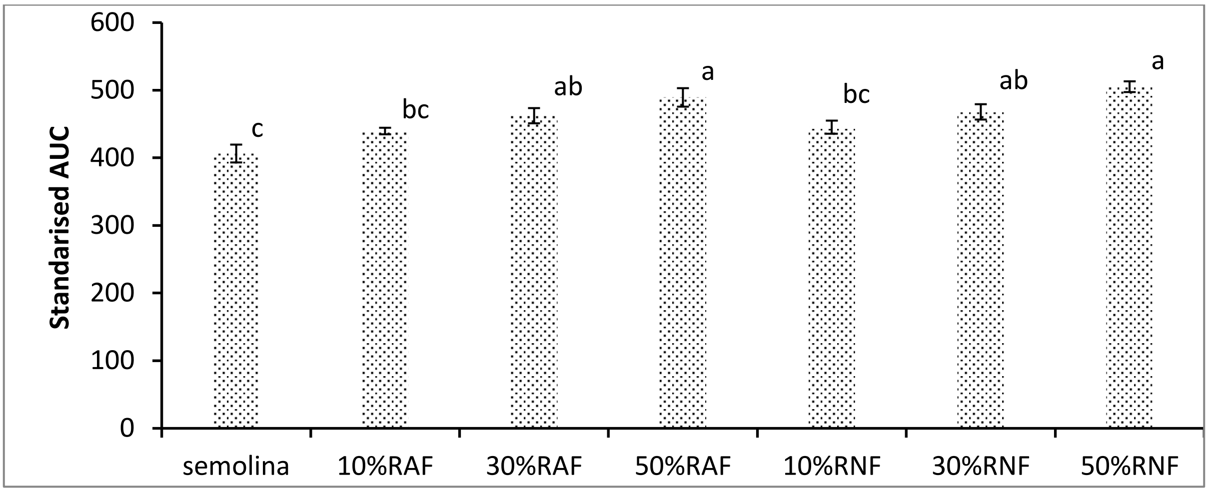
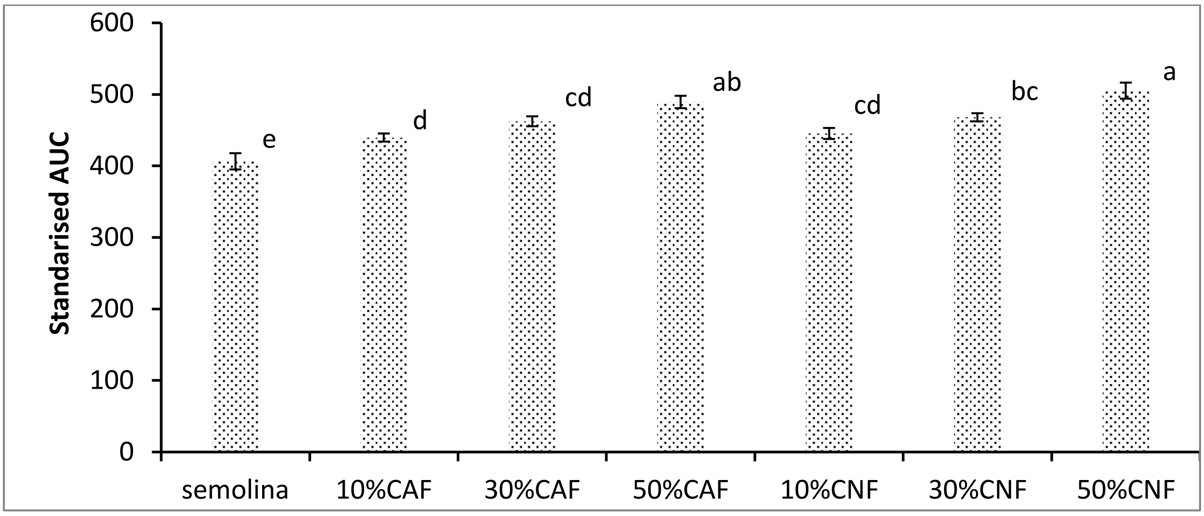


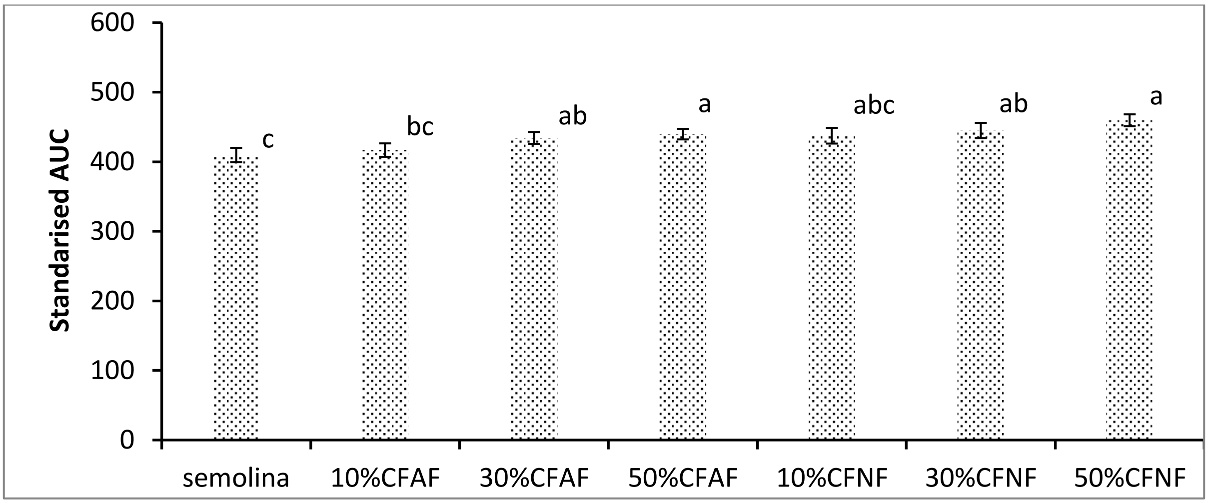
Figure 7.1 Reducing sugar released of cooked pasta fortified with potato flour
All measurements are mean values ± SD of triplicate determinations.
[a,b,c,d] Mean values within a column with unlike superscript letters are significantly different (P< 0.05; according to Tukey's test).



(a)



(b)



(c)

Figure 7.2 Values for area under the curve (AUC) for cooked pasta fortified with potato flour
All measurements are mean values ± SD of triplicate determinations.
[a,b,c,d] Mean values within a column with unlike superscript letters are significantly different (P< 0.05; according to Tukey's test).

7.6 Conclusions

This study investigated the effect of substitution of durum wheat semolina with two local cultivars of potato (Agria and Nadine) flour on viscosity, digestion properties and the quality of pasta. The addition of potato flour diluted the gluten protein and weakened the gluten network for wheat flour/potato flour system. Supplementation of potato flour influenced the texture properties of potato-wheat pasta, the addition of potato flour increased the firmness. In addition, all enriched pasta with potato flour showed a significant increase in reducing sugar released during an *in vitro* digestion and standardised AUC values compared to control pasta. Fortification improved the pasting and nutraceutical of pasta products and promoted the processing of potato staple food. The results of the current study suggest the potential for enlarging the use of potato flours in wheat pasta. However, more research is required to determine how best to achieve potato-wheat pasta with similar textural characteristics to wheat (semolina) pasta samples.

Chapter 8

The Effect of Soy Protein addition to Potato and Wheat blends on the Quality Pasta Products

Abstract

This study investigated the effect of addition 2%-4% soy protein in durum wheat semolina fortified with 30% two local cultivars of potato (Agria and Nadine) flour on viscosity, digestion properties and the quality of pasta. The quality and digestion properties of pasta was investigated, the cooking loss significantly increased by adding soy protein, but the swelling index decreased. Supplementation of soy protein also influenced the texture properties of pasta, the addition increased the firmness of the pasta. All enriched potato pasta with soy protein showed a significant decrease in reducing sugar released during an *in vitro* digestion and standardised AUC values compared to potato pasta. The results of the current study suggest the potential for enlarging the use of potato flours in wheat pasta.

8.2 Introduction

Pasta is a popular wheat-based food in most countries worldwide, due to its convenience, inexpressiveness, palatability and nutritional value (Aravind, Sissons, & Fellows, 2011). Traditionally, semolina is the preferred raw ingredient for producing high quality pasta (Feillet, 1996). However, most traditional wheat-based foods are produced from simple raw materials and may lack essential nutrients, such as amino acids, dietary fibre, vitamins, and minerals (Liu *et al.*, 2017). In the last few decades, more and more studies have paid attention to the possibility of creating wheat-based products with added-value, for instance improving the nutritional value and reducing the risk of diseases by adding rice, legume flour, tuberous roots, oat, corn, wheat germ, barely, fibre, fish, and polyphenols (Desai, Brennan, & Brennan, 2019; Lu *et al.*, 2016; Rachman, Brennan, Morton, & Brennan, 2019a; Shogren, Hareland, & Wu, 2006; Sobota *et al.*, 2015; Sun, Zhang, Hu, Xing, & Zhuo, 2015).

Potato is the most important food crop in the world and a great source of carbohydrates, it is considered as a staple food in many countries. Potato flour has been successfully used as a replacement or base material in wheat-based food (Anjum, Pasha, Ahmad, Issa Khan, & Iqbal, 2008;

Ijah *et al.*, 2014; Liu *et al.*, 2017). In wheat pasta, gluten protein provides the ideal cooking qualities and texture of products (Feillet, 1996; Katyal *et al.*, 2016). However, potato flour lacks gluten protein, and it is difficult to make pasta from the whole potato. The addition of potato flour was shown in the previous Chapter to weaken the gluten network between the protein and starch system and affect pasta quality, including colour, sensory and cooking characteristics. This has also been reported in previous studies (Padalino, Conte, & Del Nobile, 2016; Pu *et al.*, 2017).

Studies have shown that the protein content and food quality of wheat-based pasta can be improved by adding plant protein and animal protein, and the improvement effect is closely related to the protein type and the amount of added protein (Desai, Brennan, *et al.*, 2018; Rachman, Brennan, Morton, & Brennan, 2019b; Shogren *et al.*, 2006; Tazrart *et al.*, 2016). Soy protein is a good source of plant protein and has been reported to lower cholesterol levels and reduce the risk of cancer, diabetes and obesity (Friedman & Brandon, 2001). Addition of soy protein to wheat flour enhances pasta nutritional value.

Adding soy protein to wheat-based flour to make food has been a topic of interest for researchers recently. However, there are no studies which describe the effect of soy protein on the quality of potato pasta. Thus, the aim of this study was to develop new pasta from different treated potato flour fortified with soy protein and to investigate the effects of soy protein on physicochemical properties (protein, moisture and fibre content, cooking properties, and textural properties), morphological, thermal, cooking, texture and sensory properties of new potato pasta.

8.3 Materials and Methods

8.3.1 Raw Materials

Described in section 3.1

8.3.2 Preparation of Potato Flour

Described in section 3.1.1

8.3.3 Preparation of Potato-wheat Pasta Enriched With Soy Protein

Described in section 3.1.4

8.3.4 Cooking Properties of Pasta

Described in section 3.3

8.3.5 In Vitro Starch Digestibility and Glycemic Response

Described in section 3.3.6

8.4 Statistical Analysis

Statistical analysis was carried out as described in section 3.4

8.5 Results and Discussion

8.5.1 Physicochemical Properties of Potato-wheat Pasta Enriched with Soy Protein

The moisture content, protein content, and total starch content of cooked pasta samples are shown in Table 8.1, and illustrate that potato-wheat pasta had both higher moisture and total starch content. Adding 2% of soy protein isolate did not show statistical differences ($P>0.05$), but when 4% and 6% was added, a lower moisture was observed, this trend is similar to that reported previously for pasta fortified with Mexican common bean flour (Gallegos-Infante *et al.*, 2010). Ovando-Martínez, Sáyago-Ayerdi, Agama-Acevedo, Goñi, and Bello-Pérez (2009) studied pasta enriched with banana flour and found that the decrease in the moisture content of the pattern was related to the decrease in the protein content of the pasta, where the network produced by the gluten was decreased and allowed the moisture to evaporate easily. Similarly, Desai, Brennan, and Brennan (2018) found that the moisture content of pasta enriched with fish powder decreased with the amount of fish powder was added, which was due to the polysaccharide-protein interaction in pasta.

The protein content of pasta increased with an increased level of soy protein isolate in the sample (Table 7.1), this was associated with the amount of soy protein isolate added. Previous research has also shown an increase in protein when soy protein was added to pasta formulations (Rachman *et al.*, 2019b). Gallegos-Infante *et al.* (2010) reported a protein content of 16.68% for pasta with common bean flour (30%), but in potato-wheat pasta with soy protein isolate (4%-6%), protein content was 14.89%-16.98% (Table 7.1). Compared with the studies of Desai, Brennan, and Brennan (2018), the content of protein in pasta was 16.52% after adding 5% fish powder. Hence, soy protein isolate is a good source of plant protein in protein supplement.

The total starch content of pasta generally decreased with increasing soy protein isolate content. There was no difference in total starch content between different varieties and different processing methods. Reducing the starch intake and increasing protein content, it would be helpful for contribution of pasta, make this product become functional food (Segura-Campos, García-Rodríguez, Ruiz-Ruiz, Chel-Guerrero, & Betancur-Ancona, 2015).

As shown in Table 7.1, after adding soy protein isolate, the content of RS is pasta decreased significantly. The potato flour pasta showed the highest value of RS, while the pasta containing 6% of soy protein isolate possessed the lowest value. This observation was similar to that reported by Goñi and Valentín-Gamazo (2003) in pasta with added chickpea flour. There was no significant difference in RS between different potato varieties, however, the treatment of potato flour affected the RS content in pasta. It was found that the RS fraction was the highest for enriched soy protein raw potato flour pasta and lowest for 6% soy protein fortified cooked potato flour pasta. This is related to the RS content of potato flour. Yu *et al.* (2015) studied the effects of retrogradation and further acetylation on purple sweet potato flour and found that treatment affected the RS of potato flour. Resistant starches can be used in the food industry to enhance the DF content of different wheat-based products. According to Gelencsér, Gál, Hódsági, and Salgó (2008), enriched RS products release glucose slowly and is possible in the treatment of obesity and weight management, more and more researchers have focused on the apply of RS on food products (Foschia, Beraldo, & Peressini, 2017; Kolarič *et al.*, 2019).

Table 8.1 Composition characteristics of cooked potato pasta enrich with 2-6% soy protein

Formulation	Moisture %	Protein (%, g/100g)	Total starch (%, g/100g)	Resistant starch (%, g/100g)
Raw Agria potato flour & Wheat flour & Soy protein				
30%RAF	12.29 ± 0.09^{a}	11.01 ± 0.08^{d}	68.33 ± 1.21^{a}	2.56 ± 0.09^{a}
30%RAF+2%S	12.24 ± 0.11^{ab}	12.71 ± 0.12^{c}	66.91 ± 1.11^{ab}	2.10 ± 0.11^{b}
30%RAF+4%S	12.15 ± 0.09^{ab}	14.92 ± 0.09^{b}	64.26 ± 1.15^{bc}	1.46 ± 0.08^{c}
30%RAF+6%S	11.98 ± 0.15^{b}	16.18 ± 0.11^{a}	63.18 ± 0.92^{c}	1.09 ± 0.09^{d}
Raw Nadine potato flour & Wheat flour & Soy protein				
30%RNF	12.97 ± 0.12^{a}	11.19 ± 0.16^{d}	68.64 ± 1.24^{a}	1.94 ± 0.05^{a}
30%RNF+2%S	12.69 ± 0.11^{ab}	12.86 ± 0.11^{c}	67.03 ± 1.36^{ab}	1.38 ± 0.08^{b}
30%RNF+4%S	11.65 ± 0.13^{ab}	14.58 ± 0.12^{b}	64.68 ± 1.02^{bc}	1.17 ± 0.06^{c}
30%RNF+6%S	11.07 ± 0.09^{b}	15.73 ± 0.07^{a}	62.36 ± 1.11^{c}	0.94 ± 0.08^{d}
Cooked Agria potato flour & Wheat flour & Soy protein				
30%CAF	12.19 ± 0.11^{a}	10.73 ± 0.18^{d}	68.36 ± 1.04^{a}	2.99 ± 0.13^{a}
30%CAF+2%S	12.13 ± 0.09a	12.55 ± 0.14^{c}	66.12 ± 1.06^{ab}	2.13 ± 0.12^{b}
30%CAF+4%S	11.15 ± 0.13^{b}	14.84 ± 0.09^{b}	64.23 ± 1.22^{bc}	1.71 ± 0.08^{c}
30%CAF+6%S	10.76 ± 0.12^{c}	16.17 ± 0.13^{a}	62.59 ± 1.11^{c}	0.94 ± 0.09^{d}
Cooked Nadine potato flour & Wheat flour & Soy protein				
30%CNF	12.76 ± 0.12^{a}	11.27 ± 0.13^{c}	67.05 ± 1.31^{a}	2.89 ± 0.14^{a}
30%CNF+2%S	12.69 ± 0.12^{a}	13.65 ± 0.12^{b}	64.69 ± 1.06^{ab}	2.11 ± 0.12^{b}
30%CNF+4%S	11.49 ± 0.13^{b}	13.89 ± 0.11^{b}	62.56 ± 1.05^{bc}	1.72 ± 0.14^{c}
30%CNF+6%S	11.05 ± 0.09^{c}	15.63 ± 0.09^{a}	61.11 ± 1.08^{c}	0.98 ± 0.11^{d}
Cooked-Frozen Agria potato flour & Wheat flour & Soy protein				
30%CFAF	12.81 ± 0.13^{a}	10.99 ± 0.14^{c}	67.63 ± 1.09^{a}	2.47 ± 0.11^{a}
30%CFAF+2%S	12.74 ± 0.12^{a}	12.73 ± 0.12^{b}	65.69 ± 1.12^{ab}	2.06 ± 0.14^{b}
30%CFAF+4%S	11.69 ± 0.11^{b}	15.23 ± 0.08^{a}	63.55 ± 1.14^{bc}	1.65 ± 0.11^{c}
30%CFAF+6%S	10.73 ± 0.13^{c}	15.36 ± 0.11^{a}	62.32 ± 1.23^{c}	1.12 ± 0.11^{d}
Cooked-Frozen Nadine potato flour & Wheat flour & Soy protein				
30%CFNF	12.83 ± 0.12^{a}	11.01 ± 0.10^{d}	68.36 ± 1.31^{a}	1.92 ± 0.08^{a}
30%CFNF+2%S	12.59 ± 0.11^{a}	13.21 ± 0.07^{c}	66.69 ± 1.07^{ab}	1.79 ± 0.11^{ab}
30%CFNF+4%S	11.11 ± 0.15^{b}	16.36 ± 0.11^{b}	65.03 ± 1.09^{bc}	1.43 ± 0.10^{c}
30%CFNF+6%S	11.07 ± 0.12^{c}	16.98 ± 0.09^{a}	63.57 ± 1.22^{c}	1.13 ± 0.11^{d}

All measurements are mean values ± SD of triplicate determinations.
[a,b,c,d] Mean values within a column with different superscript letters are significantly different (P< 0.05; according to Tukey's test).
30% Raw Agria potato flour+70% wheat flour (30%RAF); 98%(30% Raw Agria potato flour+70% wheat flour)+ 2% soy protein(30%RAF+2%S); 96%(30% Raw Agria potato flour+70% wheat flour)+ 4% soy protein(30%RAF+4%S); 94%(30% Raw Agria potato flour+70% wheat flour)+ 6% soy protein(30%RAF+6%S);

8.5.2 Effect of Soy Protein on Cooking Loss, Swelling Index and Water Absorption Index of Potato Pasta

Cooking properties were investigated by measuring optimum cooking time, cooking loss, swelling index, and water absorption. The results are shown in Table 8.2. Previous research using potato flour as the partial ingredient has shown that the cooking quality of pasta decreased with an increasing proportion of potato flour (Kang *et al.*, 2017; Pu *et al.*, 2017). However, studies have also shown that the protein addition have improved the quality of pasta (Gallegos-Infante *et al.*, 2010; Rachman *et al.*, 2019b).

Optimum cooking time decreased (P<0.05) progressively as soy protein increased (Table 8.2), which generally agrees with a previous report of pasta enriched fish powder (Desai *et al.*, 2018). Gallegos-Infante, Bello-Perez, Rocha-Guzman, Gonzalez-Laredo, and Avila-Ontiveros (2010) studied the addition of common bean flour in spaghetti, a 20% reduction in optimum pasta cooking time at a 30% inclusion level of common bean flour. All the potato pasta fortified soy protein had a lower optimal cooking time (4.8-5.2 min) compared to previous studies of semolina pasta (Desai, Brennan, *et al.*, 2018; Rachman *et al.*, 2019b). The shorter optimal cooking time appeared to be related to lower WAI and higher CL (Table 8.2), some researchers have shown a positive correlation between optimal cooking time and water absorption (Desai *et al.*, 2019; Rodríguez De Marco, Steffolani, Martínez, & León, 2018).

CL is a popular variable to determine the quality of pasta and has become an industry standard and the industry standard of CL for the pasta is no greater than 8% (Foschia *et al.*, 2015a). The CL of potato pasta was significantly affected by the level of protein fortification, the value of CL increased with increasing levels of soy protein inclusion. This result is similar to the report by Limroongreungrat & Huang, (2007), who added soy protein into sweet potato pasta, and found an increased CL which was observed by the increasing of soy protein concentrate. This may be related to the fact that pasta with added soy protein has a higher protein content, because the higher protein content makes the structure of the pasta more porous, resulting in higher CL. Solid loss is undesirable because compounds such as starch, protein and minerals enter the cooking water and leave the pasta. The loss of solids during cooking is due to the dilution of some of the ingredients that replace semolina (Doxastakis *et al.*, 2007).

Addition of soy protein did not give significant changes in water sorption, meaning that the water binding capacity of pasta remained unchanged. These results have also been observed by other researchers who found addition of soy protein did not affect pasta WAI (CAMPOS, 2018; Rachman *et al.*, 2019b). However, Foschia *et al.* (2015a) reported that inclusion of different DF into pasta can cause a significant increase in WAI than control semolina sample.

The swelling index of pasta samples are reported in Table 8.2. Pasta prepared with 2%-6% soy protein showed significantly lower swelling index than the control pasta. Compared with different varieties and processing methods of potato flour, no difference in swelling index was observed between samples. The reduced SI could be due to the formation of a protein network in the pasta enriched with soy protein resulting in the limited supply of water for starch granule for swelling and gelatinisation. Similar results were reported by Desai *et al.* (2018), who reported that the SI decreased significantly ($P < 0.05$) as levels of fish powder (5-20 g/100 g) increased in fortified pasta.

Table 8.2 Cooking properties of cooked potato pasta enrich with 2-6% soy protein

Formulation	Optimal Cooking Time (min)	Cooking Loss (g/100 g)	Swelling Index (g water/g dry pasta)	Water Absorption Index (g/100 g)
Raw Agria potato flour & Wheat flour & Soy protein				
30%RAF	5.20	5.39 ± 0.24^{b}	2.47 ± 0.14^{a}	85.36 ± 1.72^{a}
30%RAF+2%S	5.20	5.35 ± 0.16^{ab}	2.33 ± 0.09^{ab}	83.69 ± 1.53^{ab}
30%RAF+4%S	5.10	5.67 ± 0.17^{ab}	2.15 ± 0.11^{bc}	81.46 ± 1.57^{ab}
30%RAF+6%S	5.00	5.89 ± 0.19^{a}	1.95 ± 0.13^{c}	80.02 ± 1.30^{b}
Raw Nadine potato flour & Wheat flour & Soy protein				
30%RNF	5.30	5.49 ± 0.16^{c}	2.34 ± 0.08^{a}	86.35 ± 1.29^{a}
30%RNF+2%S	5.20	5.45 ± 0.16^{c}	2.22 ± 0.06^{ab}	85.41 ± 1.35^{ab}
30%RNF+4%S	5.10	5.79 ± 0.17^{b}	1.96 ± 0.11^{b}	83.45 ± 1.12^{ab}
30%RNF+6%S	5.00	6.05 ± 0.18^{a}	1.87 ± 0.10^{b}	81.98 ± 1.18^{b}
Cooked Agria potato flour & Wheat flour & Soy protein				
30%CAF	5.30	5.15 ± 0.14^{c}	2.21 ± 0.11^{a}	86.36 ± 1.43^{a}
30%CAF+2%S	5.20	5.09 ± 0.20^{c}	2.14 ± 0.14^{ab}	85.04 ± 1.55^{ab}
30%CAF+4%S	5.10	5.36 ± 0.25^{b}	2.03 ± 0.09^{b}	83.26 ± 1.61^{ab}
30%CAF+6%S	5.00	5.73 ± 0.15^{a}	1.93 ± 0.07^{b}	81.65 ± 1.30^{b}
Cooked Nadine potato flour & Wheat flour & Soy protein				
30%CNF	5.20	5.63 ± 0.17^{c}	2.12 ± 0.11^{a}	81.21 ± 2.22^{a}
30%CNF+2%S	5.10	5.59 ± 0.11^{c}	2.06 ± 0.06^{ab}	80.26 ± 1.64^{ab}
30%CNF+4%S	5.00	5.81 ± 0.18^{b}	1.96 ± 0.08^{b}	78.95 ± 2.00^{bc}
30%CNF+6%S	4.90	6.05 ± 0.15^{a}	1.89 ± 0.07^{b}	77.03 ± 2.05^{cd}
Cooked-Frozen Agria potato flour & Wheat flour & Soy protein				
30%CFAF	4.90	5.32 ± 0.18^{c}	2.23 ± 0.06^{a}	81.35 ± 1.63^{a}
30%CFAF+2%S	4.90	5.37 ± 0.08^{c}	2.15 ± 0.09^{ab}	80.65 ± 1.62^{ab}
30%CFAF+4%S	4.80	5.71 ± 0.11^{b}	2.03 ± 0.11^{b}	78.87 ± 1.40^{bc}
30%CFAF+6%S	4.70	5.99 ± 0.14^{a}	1.96 ± 0.11^{b}	77.83 ± 1.52^{cd}
Cooked-Frozen Nadine potato flour & Wheat flour & Soy protein				
30%CFNF	5.10	5.49 ± 0.28^{c}	2.27 ± 0.12^{a}	79.43 ± 1.99^{ab}
30%CFNF+2%S	5.10	5.55 ± 0.06^{c}	2.18 ± 0.07^{ab}	78.43 ± 1.64^{ab}
30%CFNF+4%S	5.00	5.73 ± 0.10^{b}	2.06 ± 0.09^{b}	77.08 ± 1.52^{c}
30%CFNF+6%S	4.90	5.97 ± 0.11^{a}	1.88 ± 0.07^{b}	76.05 ± 1.58^{d}

All measurements are mean values ± SD of triplicate determinations.

^{a,b,c,d} Mean values within a column with unlike superscript letters are significantly different ($P< 0.05$; according to Tukey's test).

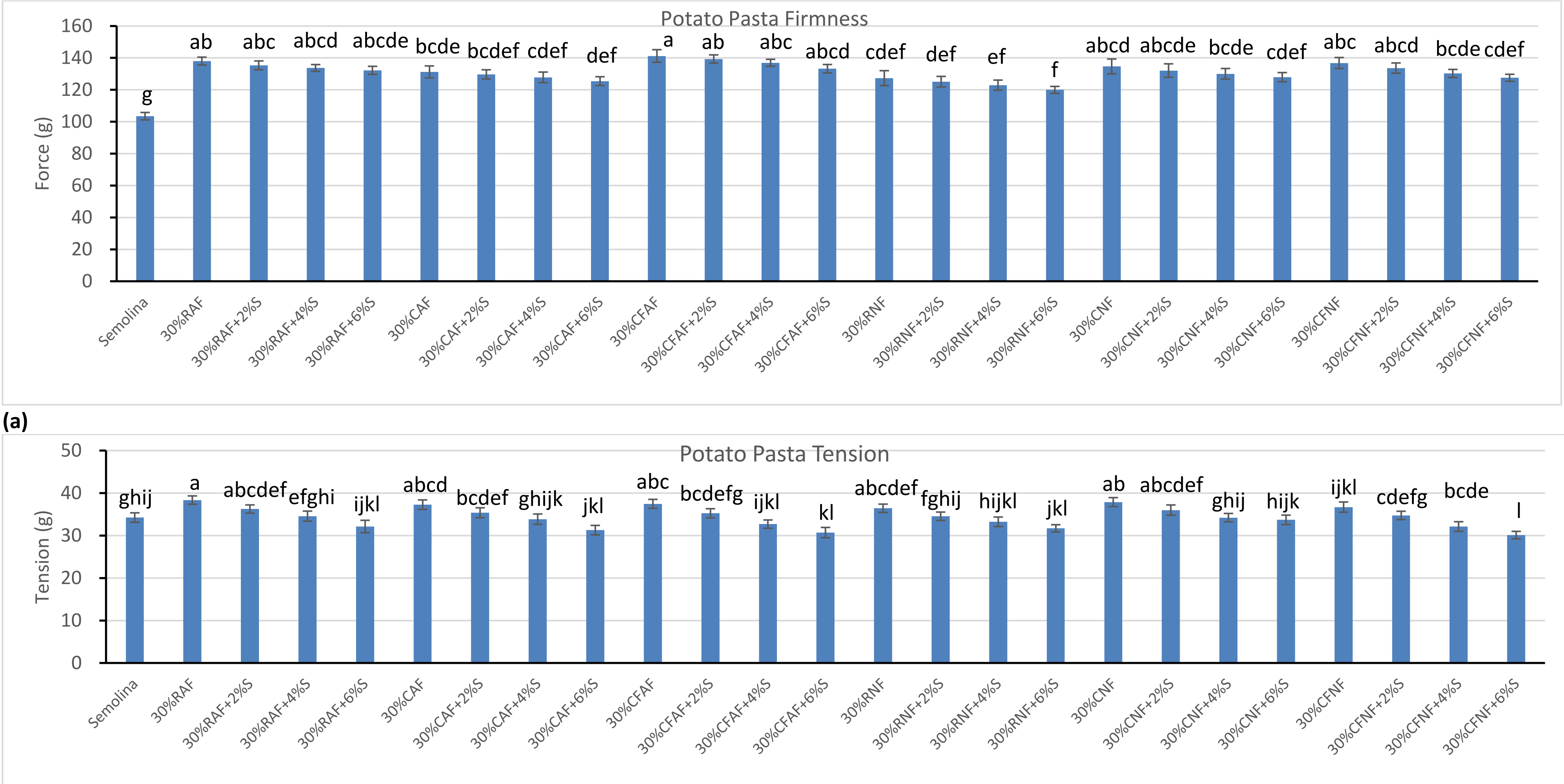
30% Raw Agria potato flour+70% wheat flour (30%RAF); 98%(30% Raw Agria potato flour+70% wheat flour)+ 2% soy protein(30%RAF+2%S); 96%(30% Raw Agria potato flour+70% wheat flour)+ 4% soy protein(30%RAF+4%S); 94%(30% Raw Agria potato flour+70% wheat flour)+ 6% soy protein(30%RAF+6%S);

8.5.3 Texture Properties of Cooked Potato Pasta Enriched With Different Soy Protein

The addition of soy protein significantly reduced firmness and tension (Table 8.1), and the hardness and extensibility of potato pasta decreased with the increase of the amount of soy protein added. Compared to the semolina pasta, the hardness of all potato pasta enriched with soy protein was higher than that of semolina pasta. The main reason may be the hardness of potato flour in potato pasta. However, when the amount of soy protein was more than 4%, the elasticity of potato pasta enriched with soy protein was less than that of semolina pasta. Therefore, the level of soy protein addition in pasta, especially potato pasta with soy protein addition of 6%, had the highest similarity with semolina pasta and should be considered as having the potential to be applied in any product development. However, previous reports have illustrated that if a large amount of soy (protein, skim, and whole flour) was added to the wheat dough, its texture will be affected. For instance, Ribotta *et al.* (2005) showed that, as a result of dough mixing, soy protein interferes with gluten formation in both direct and indirect ways, directly related to the interaction between soy and gluten, and indirectly related to the availability of wheat protein due to the modification of water. The competition between soy protein and gluten for water molecules led to the destruction of the starch-protein complex.

From a production point of view, using coarse powder alone may maintain the texture of cooked pasta, so that the [pasta may be able to resist surface disintegration, and maintain a firm structure. The substitution of gluten presents a significant technical challenge since gluten is an essential structural building protein that is essential for the preparation of high quality cereals (Gallagher, Gormley, & Arendt, 2004). The interaction between gluten and soy protein has the potential to enhance dough properties due to the ss-sh exchange between the thiol groups of soy protein and gluten chains. Instead, the negative effects associated with soy-wheat bread (less elastic matrix, lower gas retention, reduced volume, and increased air cell density) are due to the reduced interaction between gluten proteins due to the dilution of gluten proteins in soy (Ryan *et al.*, 2002).

Substituting soy protein (up to 6%) for potato pasta, the overall protein content of the composite formula remains at 16 %, higher than that of semolina pasta (13 %), and does not negatively affect the texture and is acceptable.



(a)

(b)

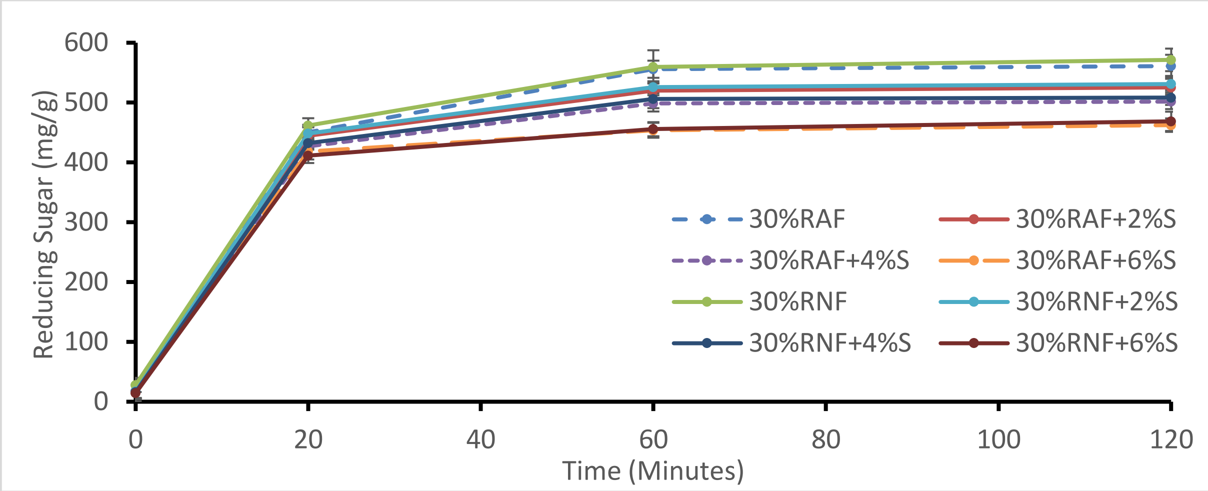
Figure 8.1 Texture properties of cooked potato pasta enriched with different soy protein

30% Raw Agria potato flour+70% wheat flour (30%RAF); 98%(30% Raw Agria potato flour+70% wheat flour)+ 2% soy protein(30%RAF+2%S); 96%(30% Raw Agria potato flour+70% wheat flour)+ 4% soy protein(30%RAF+4%S); 94%(30% Raw Agria potato flour+70% wheat flour)+ 6% soy protein(30%RAF+2%S).

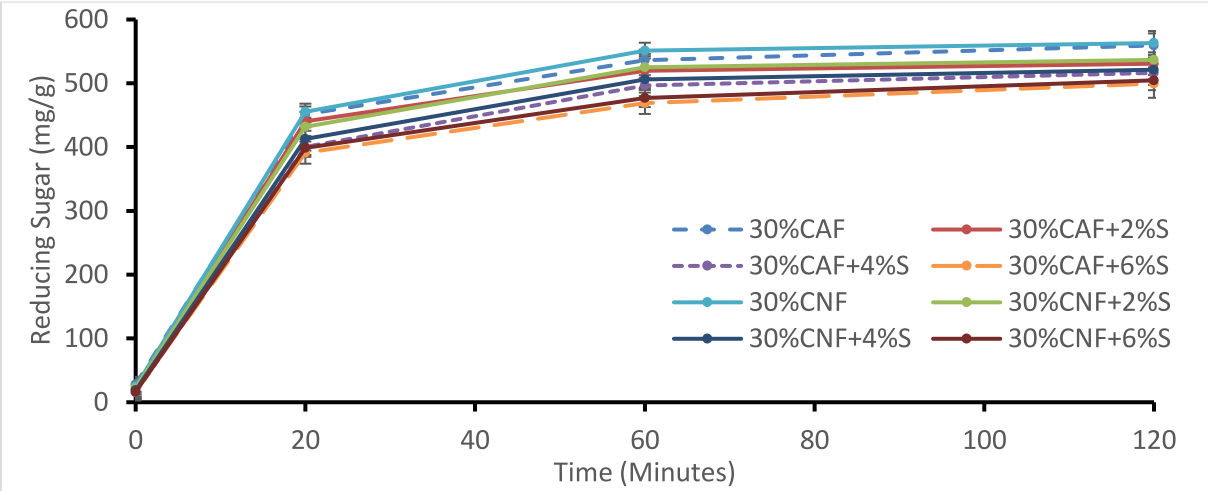
8.5.4 *In vitro* digestion of cooked potato pasta enriched with different soy protein

There are a large number of studies evaluating the starch digestibility of traditional durum semolina pasta as well as that fortified with non-traditional ingredients (Gelencsér *et al.*, 2008; Rachman *et al.*, 2019a; Segura-Campos *et al.*, 2015).

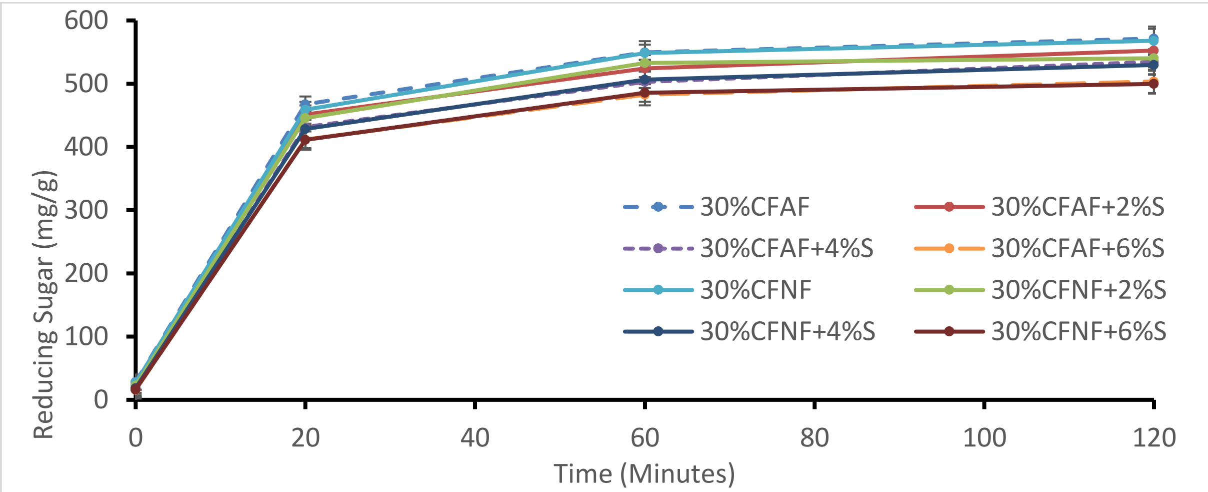
An *in vitro* enzymatic digestion was performed to evaluate the nutritional quality of the potato pasta enriched with soy protein to determine their starch digestibility and predictive glycemic response. Figure 8.2 illustrates that the potato pasta (30% potato flour pasta and protein fortified) exhibited a glucose release in a progressive manner. This is consistent with previous report about sweet potato pasta fortified protein (Gopalakrishnan, Menon, Padmaja, Sajeev, & Moorthy, 2011). The addition of soy protein into potato pasta decreased ($P < 0.05$) the extent of *in vitro* starch digestion compared to the control 30% potato pasta (Figure 8.2). In all samples, the values of reducing sugars increased dramatically in the first 20 min and the peak values were reached between 20 min and 60 min. The release of reducing sugars was significantly higher in the control pasta than from all the soy protein enriched potato pasta samples. The potato pasta enriched with 6% soy protein exhibited significantly lower values ($P < 0.05$) of reducing sugar compared to the control sample, followed by 4% soy protein fortified and 2% soy protein fortified pasta samples, while the control 30% potato pasta showed the higher values at each time point during the digestion. Gallegos-Infante *et al.* (2010) reported that addition of Mexican bean flour rich soy protein into spaghetti significantly lowered the reducing sugar. The addition of soy protein may create a protein network around the starch molecules and reduce the starch granules surface accessibility of α-amylase to starch and hence affect the enzyme susceptibility to hydrolysing the starch into reducing sugar. It has been reported previously that the presence of protein in food matrix creates a stronger network and reduces the capacity of enzyme attack to the starch granules, thereby delaying starch digestion (Gallegos-Infante *et al.*, 2010). The soy protein used in this study may also decrease the reducing sugar release due to the formation of protein network which entraps the α-amylase. Compared with different potato varieties, the reducing sugar release of potato flour pasta enriched soy protein was significantly different.



a



B



c

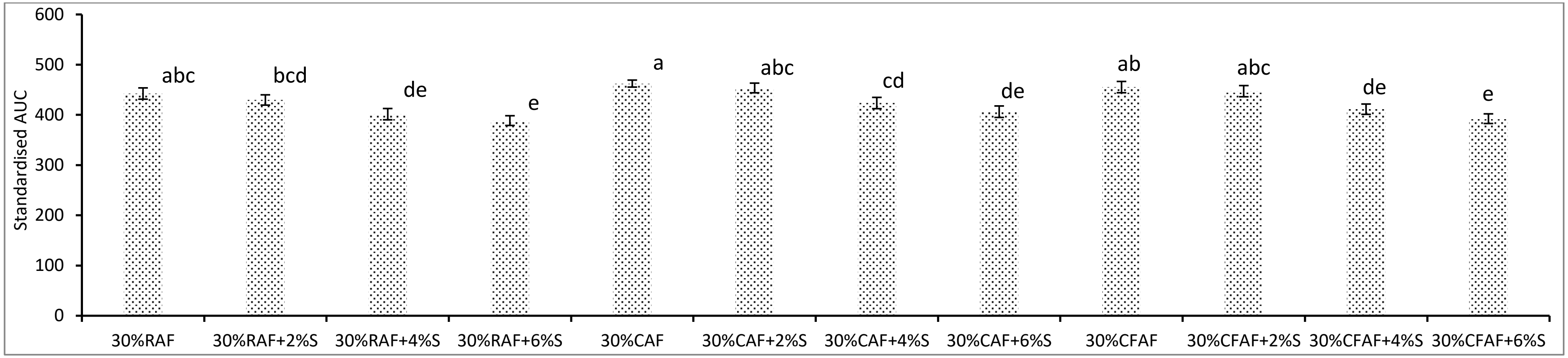
Figure 8.2 Levels of reducing sugars released during in vitro digestion

All measurements are mean values ± SD of triplicate determinations.

[a,b,c,d] Mean values within a column with unlike superscript letters are significantly different ($P < 0.05$; according to Tukey's test).

30% Raw Agria potato flour+70% wheat flour (30%RAF); 98%(30% Raw Agria potato flour+70% wheat flour)+ 2% soy protein(30%RAF+2%S); 96%(30% Raw Agria potato flour+70% wheat flour)+ 4% soy protein(30%RAF+4%S); 94%(30% Raw Agria potato flour+70% wheat flour)+ 6% soy protein(30%RAF+6%S);

Figure 8.3 illustrates the effects of potato pasta fortified with 2-6% soy protein on standardised AUC values. The AUC values decreased in potato pasta fortified with soy protein. The potato pasta fortified with 6% soy protein showed the lowest of the AUC values. The AUC values decreased gradually with the addition of soy protein. Previous work has indicated that when co-products from chestnut mushroom were added to extruded snack products, they restricted the amount of readily digestible carbohydrates in extruded samples compared with a control sample (Brennan, Derbyshire, Tiwari, & Brennan, 2012). The rate of digestion of carbohydrates present in the food controls the glycemic impact of foods, thus high GI foods, in which the carbohydrate fractions are digested and absorbed rapidly, result in marked fluctuations in blood glucose levels (Foschia *et al.*, 2015b). The rate, and extent, of carbohydrate digestion are governed by factors such as the structure and composition of starch, as well as the amount of fibre, protein and fat within a product (Dona, Pages, Gilbert, & Kuchel, 2010).



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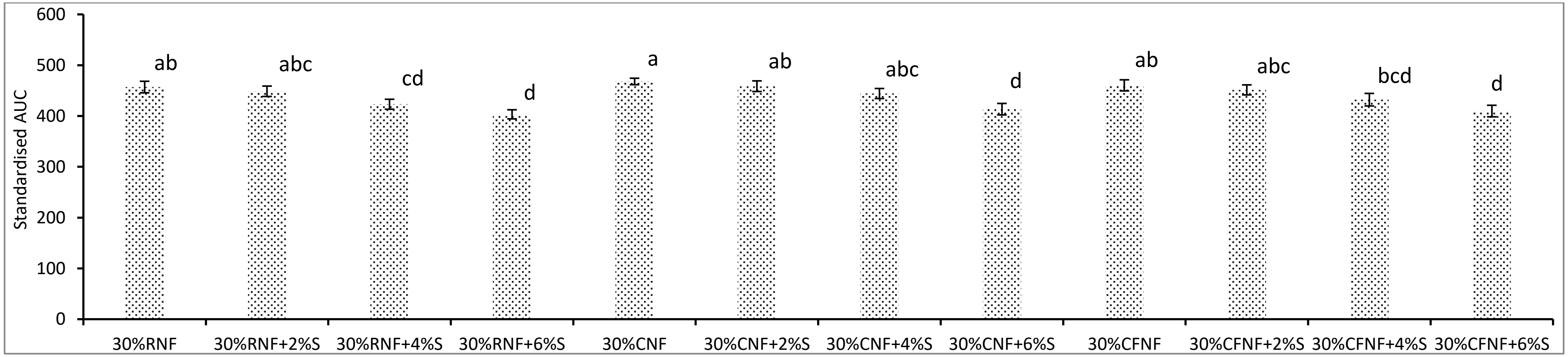

b

Figure 8.3 Area under curve (AUC) values of potato pasta fortified with 2-6% soy protein

All measurements are mean values ± SD of triplicate determinations.

[a,b,c,d] Mean values within a column with unlike superscript letters are significantly different (P< 0.05; according to Tukey's test).

30% Raw Agria potato flour+70% wheat flour (30%RAF); 98%(30% Raw Agria potato flour+70% wheat flour)+ 2% soy protein(30%RAF+2%S); 96%(30% Raw Agria potato flour+70% wheat flour)+ 4% soy protein(30%RAF+4%S); 94%(30% Raw Agria potato flour+70% wheat flour)+ 6% soy protein(30%RAF+6%S);

8.6 Conclusions

Fresh semolina pasta is a type of starchy food and widely consumed around the world, however, pasta is considered to be nutritional imbalanced. Potato is increasingly used in food products because of their unique nutrition and convenience. High protein pasta, with low starch digestibility was developed from two different varieties potato, using soy protein sources. The quality, and digestion properties, of pasta was investigated, the cooking loss was significantly increased by adding soy protein but decreased the swelling index. Moreover, supplementation of soy protein also influenced the texture properties of pasta, the addition of potato flour increased the firmness and as the amount added increased and then decreased. In addition, all enriched potato pasta with soy protein showed a significant decrease in reducing sugar released during an *in vitro* digestion and standardised AUC values compared to potato pasta. Fortification improved the pasting and nutraceutical of pasta products and promoted the processing of potato staple food. The results of the current study suggest the potential for enlarging the use of potato flours in wheat pasta and a low glycemic food suited to type 2 diabetic patients, obese patients and weight conscious people.

Chapter 9

General Discussion and Conclusions for Future Work

9.1 Aims and Summary

This Chapter concludes the results section and the summary of the research questions, according to the research results of this thesis. This Chapter also discusses the future direction of work. The purpose of this research was to evaluate potato flour for use in food products, and to explore the main objectives:

1. Six potato flours were obtained through three different processing methods of two different potato varieties. The physicochemical, viscosity and digestion properties of these six potato flours were compared to provide a reference for the application of potato flour.

2. Explore the mixing of these 6 different potato and wheat flour blends to provide a basis for the application of the blends in food products.

3. The application of potato flour in pasta was discussed, and the physicochemical and texture properties of potato pasta were determined.

4. The study also evaluated the nutrition and function of potato pasta and expounded the advantages and disadvantages of potato pasta.

5. Evaluate the nutrition and function of this new type of pasta by adding soy protein to potato pasta to promote the application of potato as a staple food and meet people's demand for a new kind of food.

This study demonstrated the promising application of potato powder in pasta. Before exploring potato application, two native potato varieties (Agria and Nadine) from New Zealand were investigated. It was found that different chemical composition led to differences in the physical and chemical properties of potato flour, which eventually affected pasting and blood glucose. The physicochemical and pasting properties of potato flour, wheat flour, and its mixture with potato flour were measured. These works finally verified the application of potato flour in pasta, and soybean protein was added to provide the nutrition and function of potato pasta.

9.2 General Discussion

In chapters 1 and 2, the latest literature on the physicochemical properties and nutritional value of potatoes were summarised. The debate over the nutritional benefits of potatoes and the health risks associated with potatoes were discussed, which were mainly related to the relationship between potato starch digestibility and blood glucose response. Then the classification, composition, digestion, function, and application of potato starch in food were examined. The application of potato in flour products, and the effect of potato starch on the digestion and cooking quality of grains such as pasta and noodles were analysed. Based on the summary of the previous research results, the development of potato staple food in the future was discussed. The primary purpose of this thesis was to develop the application of potato staple food, from how to produce potato flour, to prove the feasibility of potato flour products finally.

Chapter 3 described the instruments, reagents and analysis method involved in this thesis, the sources and references of the primary measurement methods, including the improvement of some measurement methods were also provided.

In Chapter 4, Agria and Nadine potatoes were used in three different ways to produce potato flour, namely raw potato flour (RAF and RNF), cooked potato flour (CAF and CNF), and cooked-frozen potato flour (CFAF and CFNF). The high dry matter content of Agria potato was found to be more conducive to the production of potato flour, Mareček *et al.* (2020) also demonstrated that potato varieties with high dry matter content were more suitable for industrial production. The total starch content of raw potato and cooked potato was similar. The content of amylose and RS were reduced in the cooking process, and potato flour also showed a similar trend in the cooking process, which was consistent with the reports in the literature (Murniece *et al.*, 2011; Šimková, Lachman, Hamouz, & Vokál, 2013). Cooked and frozen potatoes were shown to contain more RS and amylose than heated potatoes, mainly due to the retrogradation of starch, additionally the IDF content also increased. The RS produced by cooked-frozen potato starch belonged to RS3, and the amount of DF produced by the production of RS was increased (Thed & Phillips, 1995; Jinhu Tian, Jianchu Chen, Xingqian Ye, & Shiguo Chen, 2016; Yadav, Sharma, & Yadav, 2009). The SI, WAI and swelling of potato flour treated with three different methods were investigated and the content of phosphorus was negatively correlated with the WSI and positively correlated with the swelling capacity. Kikuta *et al.*, (2011) studied the correlations between the properties of starches isolated from twelve potato varieties in different parts of the world and found the same pattern. In the pasting characteristic parameters, the peak represents the swelling capacity of the sample, trough and breakdown represented the stability and shear resistance of the gelatinised sample, setback and final viscosity represented the retrogradation characteristics of the sample and the ability to increase the consistency of the food system (Balet, Guelpa, Fox, & Manley, 2019). In the entire testing process, the cooked potato flour (CAF and CNF) always showed the highest viscosity, and the cooked-frozen potato flour (CFAF and CFNF) showed the lowest viscosity among the flour samples. Zaidul, *et al*. (2007) studied the correlation between the components of various potato starch and the viscosity characteristics (RVA), and indicated that amylose negatively correlated with peak viscosity and breakdown, and positively correlated with the setback. However, Higley, Love, Price, Nelson, and Huber (2003) observed that the peak viscosity of mealy potatoes with higher amylose content was higher than that of waxy potatoes. Wiesenborn, Orr, Casper and Tacke (1994) suggested that amylose content had no significant effect on peak viscosity. In our study, high amylose potato negatively correlated with peak viscosity and the breakdown, and positively correlated with final viscosity, peak viscosity temperature, and setback. The *in vitro* digestibility of the RVA gel of potato flour refined from the three different processing methods was evaluated. When the cooked potato was cooled or frozen for a period after cooking, the *in vitro* digestibility of starch decreased. The main reason for the difference was that the treatment method changed the content of RS in potato flour. Cooked potato flour contained the most amount of digestible starch. García ‐ Alonso and Goñi (2000) assessed the contents of digestible and RS in processed potatoes, and their findings agreed with our conclusions. Compared to Agria potatoes, Nadine had a higher blood sugar response and was easier to digest. The possible cause was that different amylose levels interfered with digestion (Leeman *et al.*, 2006). Therefore, potato and their products produced a different glycemic response, which depended on the variety of potato, starch structure, and processing method. The different physical and chemical characteristics affected the nutrition and function of potato flour.

The functional and pasting characteristics of wheat flour, and their blends with three different treatment of potato flour at 10 to 50% were investigated in Chapter 5, and the effect of the characteristics of the mixtures was studied in terms of the change of protein, total starch, amylose, dietary fibre, RS, solubility, swelling capacity, water absorption, and pasting properties. In terms of total starch content, when the potato flour quantity was increased, the total starch of potato flour and wheat flour blends also increased, which was affected by the total starch content of the potato flour. Comparison of amylose, RS, and DF in blends with different proportions, illustrated that differences were related to the composition and process of raw materials. When potato flour was added, the amylose in the mixture decreased, but there was an increase the RS and the dietary fibre content in the blends. Therefore, compared with wheat flour, the blends with potato flour have higher nutritional value. Ijah *et al.* (2014) mixed wheat and potato flour to produce bread and examined microbial, nutritional, and sensory qualities. He also found that the enrichment of potato flour increased the nutritional value, and the bread yield was higher. The use of potato flour in bread production was beneficial. In this study, substituting potato powder (10-30%) improved the water binding ability of the mixture. However, when the potato flour content increased to a certain level (more than 40%), the starch granules were easily destroyed by shear forces. From this point of view, the addition of potato flour had an adverse impact on the quality of blends. Therefore, the added amount of potato flour should be controlled within a certain range to ensure the production of pasta with consumer appeal (30% was the most appropriate). Xu, Hu, Liu, Dai, and Zhang (2017) added potato particles to wheat flour and developed noodles and bread, in their research they suggested that 20% of potato granules should be added to the noodles as the most suitable formula. The excessive addition of potato powder was harmful to quality. While the research of this thesis encourages substituting potato flour for part of the wheat flour used in wheat-based food products, when the potato flour was added in the range of 20%-30%, the functional properties of blends was moderate, and the viscosity gradually increased. Further work is needed to determine the interaction between potato flour and wheat flour and application in food products and to explain their rheological properties using DSC and rheometer.

In Chapter 6, semolina was replaced with two local cultivars of potato (Agria and Nadine) flour into pasta at 10%, 30% and 50% levels, and the effects on the physicochemical properties (CL, WAI, SI and colour) and textural properties (firmness and extensibility) of the potato pasta samples were evaluated compared with the semolina pasta. Pasta with potato flour substitution showed a significant increase in cooking loss compared with the wheat flour pasta, and potato flour incorporation negatively affected the cooking quality of pasta, which was regard as being caused by the weakening or destruction of the protein-starch matrix. Previous research had illustrated that such a disruption of the protein-starch matrix does negatively affect product quality of cereal foods (Izydorczyk *et al.*, 2005). Among all potato pasta samples, the control pasta had the lowest dry matter water absorption and CL (Table 6.1 and Table 6.2). High water absorption, low CL, and acceptable texture (high hardness and low viscosity) can be defined as high cooking quality (Bruneel *et al.*, 2010). Compared with wheat flour pasta, the CL of potato pasta in the cooking process was within the acceptable range (4%-7%). The texture is often considered the most important quality aspect of cooked pasta. From the consumer's perspective, high WAI, low CL, and appropriate texture (high hardness and low viscosity) can be defined as high cooking quality (Larrosa, Lorenzo, Zaritzky, & Califano, 2016). The research in this thesis showed that adding a certain proportion of potato flour can enhance the texture of pasta, when the amount of potato flour added exceeded a certain range, the texture of pasta began to deteriorate.

In Chapter 7, the effect of substitution of durum wheat semolina with two local cultivars of potato (Agria and Nadine) flour was investigated in terms of viscosity, digestion properties and the quality of pasta. Compared with durum wheat semolina pasta, it was found that the addition of potato flour increased the starch content in the mixture and pasta but decreased the amylose and RS. The peak viscosity, final viscosity and setback were significantly increased by adding potato flour but decreased the pasting temperature. Many researchers have reported the effect of potato starch on the increase or decrease of paste viscosity. Zaidul, Yamauchi, Kim, *et al.* (2007) studied the pasting characteristics of wheat flour and potato starch mixtures with different amylose contents. In this thesis it was found that the peak viscosity, valley value, final viscosity, retrograde viscosity, and the peak time of potato starch in the control group were higher than that of wheat flour. The peak viscosity increased significantly with an increase of potato starch in the mixture. Nawaz *et al.* (2019) studied the substitution of five different levels of potato flour for wheat flour, and the results showed that the gelatinisation properties such as peak viscosity, viscosity, decomposition, and final viscosity decreased with the addition of potato flour. In addition, all enriched pasta with potato flour showed a significant increase in reducing sugar released during an in vitro digestion and standardised AUC values compared to control pasta. However, Englyst *et al.* (2003) reported that potato starch contains RS and dietary fibre, which causes satiety and produces low blood sugar and insulin responses in the body, these effects promote weight control and control in patients with type 2 diabetes. Therefore, the addition of potato flour within a certain range has the potential as a healthy diet choice.

In Chapter 8, the effect of addition 2%-4% soy protein in durum wheat semolina fortified with 30% two local cultivars of potato (Agria and Nadine) flour was investigated in terms of viscosity, digestion properties and the quality of pasta. The addition of protein reduced the moisture content of pasta, this trend as reported previously for pasta fortified with mushroom powder (0-12%), Bengal gram flour (0–20%) and defatted soy flour (0-15%) (Kaur *et al.*, 2013). This is consistent with previous research, an increase in protein when soy protein was added to pasta formulations (Rachman *et al.*, 2019b). however, adding soy protein isolate, the content of RS is pasta decreased significantly, the potato flour pasta showed the highest value of resistant starch, while the pasta containing 6% of soy protein isolate yielded the lowest value. These results were similar to those reported by Goñi and Valentín-Gamazo (2003) in pasta with added chickpea flour. Optimum cooking time decreased ($P<0.05$) progressively as soy protein increased (Table 7.2), which generally agrees with a previous report of pasta enriched fish powder (Desai *et al.*, 2018). The CL of potato pasta was significantly affected by the level of protein fortification. Addition of soy protein did not give significant changes in water sorption, meaning pasta water binding capacity remained unchanged. These results were also observed by other researchers who found addition of soy protein did not affect pasta WAI (Campos, 2018; Rachman *et al.*, 2019b). The addition of soy protein significantly reduced firmness and tension, and the hardness. The extensibility of potato pasta decreased with an increase of the amount of soy protein added. Guo, Sun, Zhang, Wang, and Yan (2018) showed that, as a result of dough mixing, soy protein interferes with gluten formation in both direct and indirect ways, directly related to the interaction between soy and gluten, and indirectly related to the availability of wheat protein due to the modification of water. The competition between soy protein and gluten for water molecules, the destruction of the starch-protein complex. The addition of soy protein into potato pasta decreased ($P < 0.05$) the extent of *in vitro* starch digestion compared to the control 30% potato pasta, the AUC values decreased gradually with the addition of soy protein. Previous work has indicated that when co-products from chestnut mushroom were added to extruded snack products, they restricted the amount of readily digestible carbohydrates in the extruded samples compared with a control sample (Brennan *et al.*, 2012)

9.3 Recommendation for Future Work

This study demonstrated the promising application of potato powder in pasta. Before exploring potato application, two native potato varieties (Agria and Nadine) from New Zealand were investigated. These works finally verified the application of potato flour in pasta, and soybean protein was added to provide the nutrition and function of potato pasta.

Further work is needed to determine the interactions between potato flour and wheat flour and application in food products and to explain their rheological properties using Differential Scanning Calorimetry (DSC). The use of DSC enables determination of melting, crystallization, and mesomorphic transition temperatures, and the corresponding enthalpy and entropy changes, and characterization of glass transition and other effects that show either changes in heat capacity or a latent heat (Schick, 2009). DSC was used to analyse the standard network formed between different components during gelatinization, which helped to determine the correlation between the sensitivity of starch to sugars (high affinity of polysaccharides to water molecules) and the stability of starch granules.

However, adding a certain percentage of potato flour can improve the quality of pasta. When the potato flour is added beyond a certain range, the quality of pasta begins to decline. Future research is needed to determine the molecular interactions between starch and protein in potato pasta and how molecular bonding and confirmation affects pasta quality.

All enriched pasta with potato flour showed a significant increase in reducing sugar released during an *in vitro* digestion and standardised AUC values compared to control pasta. However, there is also literature describing that the addition of potato flour reduces the blood glucose response of the product, and potato flour is inhibited when it is digested in the body. Further studies are needed to assess *in vivo* digestibility to determine the extent to which potato powder provides a fermentable substrate for colonic bacteria to maximize health benefits.

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